F. DANIEL

GENERAL SCIENCE FOR TROPICAL SCHOOLS

BOOK I

SECOND EDITION

OXFORD UNIVERSITY PRESS

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FOR TROPICAL SCHOOLS

BOOK I

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BY

F. DANIEL

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GENERAL SCIENCE FOR TROPICAL SCHOOLS

By F. DANIEL

A four-year course for secondary schools, especially written for use in tropical and sub-tropical areas. It consists of four books (I–IV), with an optional volume on Health Science (IIIA). There is also a Teacher's Handbook, which gives practical suggestions for the design and equipment of laboratories, lists of apparatus necessary for this General Science course, and useful hints arising out of the author's experience in conducting it.

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By A. ATKINSON *and* F. DANIEL

A graduated series of learning and testing exercises, in two books, designed to help the student to master the facts and principles presented in the General Science textbooks. Workbook I is for use with Books I and II of *General Science for Tropical Schools*; Workbook II is for use with Books III and IV.

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By F. DANIEL

A self-contained textbook *designed primarily for students not following the author's General Science course*, and covering the syllabus in Health Science for the Cambridge Oversea School Certificate.

SUMMARIZED CONTENTS OF BOOKS I, II, III, IIIA, IV, AND TEACHER'S HANDBOOK

BOOK I: THE AIR. MATTER. THE GASES OF THE AIR. PLANT LIFE. WATER. MEASUREMENT.

APPENDICES: A. General Instructions for Science Classes. B. Scientific Apparatus and Diagrams. C. Weighing. D. Accuracy.

BOOK II: LIMESTONE, SALT AND THEIR DERIVATIVES: carbon dioxide—common salt—hydrogen chloride—chlorine—acids, bases, and salts.

PROPERTIES OF MATTER: surface tension—air pressure—liquid pressure.

PLANT LIFE: leaves—photo-synthesis—respiration—transpiration—importance of water. Flowers; pollination and fertilization. Fruits and seeds.

THE SOIL: formation—constituents—mineral matter—organic matter—air and water in the soil—plant food—micro-organisms—manures—composting—crop rotation.

SOUND: vibration—waves—resonance—musical instruments.

BOOK III: HEAT: temperature and thermometers—expansion—movement of heat—ice, water and steam—humidity—quantity of heat—change of state—latent heat—heat and work—heat engines.

ANIMAL LIFE: the highest animals—food and digestion—transport—respiration—excretion—cells and tissues.

OTHER LIVING THINGS: the simplest living things—evolution—non-flowering plants—invertebrates—lower vertebrates.

LIGHT: nature and laws—reflection—refraction—lenses—optical instruments—colour.

MAGNETISM: properties of magnets—the Earth's magnetism—electro-magnets.

APPENDIX: Practical work on animals.

BOOK IV: CHEMISTRY: chemical theory—common elements and their compounds—carbon and its compounds—food-stuffs.

PHYSIOLOGY: structure and functions of living matter; nutrition, respiration, excretion and movement in plants and animals; how living things behave; growth and reproduction in plants and animals.

MECHANICS: motion and force—work, power, and energy—machines—forces in equilibrium—motion—time and space—the solar system.

ELECTRICITY: electric charges and electric currents—effects produced by electric currents—measurement of electricity—motors, dynamos, and power supplies—transformers—telegraphs and telephones—the nature of electricity.

BOOK IIIA: (HEALTH SCIENCE): Healthy living; food and nutrition. HYGIENE: of the digestive system; of the respiratory system; of the blood system; of the skeletal, muscular and nervous systems; of the skin. The conquest of disease. Public health. Food tables.

TEACHER'S HANDBOOK

The aims, scope, and teaching of General Science; accommodation, equipment, and laboratory management; list of apparatus, tools, and materials required; sketch-plans of science rooms and store; teaching methods; running notes on Books I–IV and additional experiments; bibliography; examination papers.

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PREFACE TO SECOND EDITION

During the fifteen years that have elapsed since these books were first published, General Science teaching has expanded rapidly, and half-a-million copies of the books have been used in oversea schools. During the same period, there has been a steady improvement in the qualifications and experience of oversea science teachers, in school science equipment, and in the educational attainments (particularly in English) of oversea students following this General Science Course. At the same time, science itself has progressed; new scientific facts have emerged, and some of the older theories have been modified. Minor amendments were made in successive reprintings of the first edition, but more extensive revision has had to await the preparation of this new edition. The original textbooks have had a far-reaching influence on science teaching in oversea schools and it is hoped that this new edition will provide increasing numbers of oversea students with a better preparation for life in this scientific age.

F. DANIEL

Note.—The *Teacher's Handbook* that accompanies this General Science Course is designed to help the teacher to use the textbooks to the best advantage.

ACKNOWLEDGEMENTS

Thanks are due to the following for permission to reproduce the illustrations enumerated:

Irvine: *West African Botany*, figs. 32, 40, 41, 42, 43, 44, 48, 50, 51, 52, 53, 55; Skene: *School Botany*, fig. 35; Hart: *An Introduction to Physical Science*, fig. 79; all published by the Oxford University Press. Fig. 37 was re-drawn by Mr. Leong Pak Cheong after Godwin, Threlfall, *et alia*.

NOTE

Explanation of New Words and Technical Terms

In the text, the asterisk sign (*) is used to mark the first appearance of a general word that is not included in the standard vocabulary on which this course is based. Such words are defined in the Glossary on pp. 185–92.

The dagger sign (†) marks the first appearance of a new scientific word or technical term. Such words are also marked (†) in the Index so that the student can refer back to where they were first used and explained in the text.

The student should not part with this book. In studying Books II–IV he may want to refer back to the Glossary and to the Technical Terms marked with a dagger sign (†) in the Index.

INTRODUCTION

WHAT THIS SCIENCE COURSE IS ABOUT

When you see something that you have never seen before, your first thought is, 'What is it?' Then you ask yourself, 'What does it do?' Later on, if you have an inquiring mind, you will want to know, 'How does it work?'

One of the main objects of this 'General Science' Course is to provide the answers to such questions, and thus explain to you the world in which you live.

You will realize at once that 'General Science' is going to be a very wide subject. The word *science* comes from the Latin word *scientia*, which means *knowledge*. But our modern word *science* means something more than knowledge: it means *classified* knowledge*. We shall begin by classifying together all the things that are related to one another, and then we shall study these classes of things.

First of all, therefore, we shall draw a clear dividing line between those things which are *alive* and those which are *not alive*; that is, we shall classify all the things in the world into two main classes: (*a*) *The Living Things*, and (*b*) *The Non-Living Things.*

LIVING THINGS—PLANTS AND ANIMALS

When we speak of *living things* we probably think at once of things that move; but later on in this science course we shall meet some living things that remain still for quite a long time, yet we have all seen many non-living things moving, e.g. a piece of paper blown by the wind, a stone thrown from the hand, a sailing-boat driven by the wind, a railway train drawn by an engine, water flowing downhill, tides rising and falling. We shall find, however, that a living thing *moves of itself*, while a non-living thing moves because it is pulled or pushed by something outside itself—by some outside force. All living things, too, need *food* and *water*, part of which they use to build up their own bodies—so that *growth* takes place. We shall also find that all living things *breathe*; and, most remarkable of all, they can produce young ones and so *reproduce* themselves.

Some of the chief ways in which living things are different from non-living things, therefore, are

(*i*) *Living things breathe, feed, and grow* (non-living things do not);
(*ii*) *Living things can move of themselves;* and
(*iii*) *Living things can reproduce themselves* (non-living things cannot).

Living things, again, are divided into two main classes: (*a*) *Plants*, and (*b*) *Animals*.

You may think that you could decide at once whether any particular living thing you saw was a plant or an animal, because most of the animals you know can move about freely, while most of the plants you know do not move about and they are green in colour. But you will find that this is not always as easy as you think, until you learn the really important differences between these two classes of living things—plants and animals.

NON-LIVING THINGS—AIR, WATER, EARTH

Before we can study living things properly, we must find out something about the non-living part of the world that surrounds plants and animals, and without which they cannot live. These non-living things may be put under the three headings: (i) *Air*, (ii) *Water*, and (iii) *Earth*.

You will learn later how green plants make use of simple, non-living things from each of these three sources—air, water, and earth—and change them into more complicated materials; and how animals, in their turn, make use of food-stuffs built up by plants.

You should now have a little clearer idea of what this 'General Science' Course is about. We are going to find the answers to a lot of questions about the things of everyday life—about non-living things; mainly air, water, and earth; and about living things: plants and animals. The questions are these: 'What is it?' 'What does it do?' and 'How does it do this?'

Note.—Before beginning Chapter I, the student should read the General Instructions for Science Classes in Appendix A. He should then learn the names and uses of the scientific apparatus* described in Appendix B and, at the same time, learn how to draw simple diagrams.*

CHAPTER I

THE AIR

WHAT IS AIR?

Our first step in this science course is to find out something about one of the commonest things in the world—the *air* around us. We have become so used to being surrounded by air which we cannot see, or taste, or smell, that we often forget that it is there at all. We notice the air, however, when we move quickly through it while running, bicycling, or motoring; or when the air moves past us, as when the wind blows. Yet it is rather difficult to realize that air is a material substance, just as earth or water is. We can have a pint of water or a ton of earth. Can we have a pint of air or a ton of air? That is, does air occupy* space, or take up room, and does it have weight?

DOES AIR OCCUPY SPACE?

If an 'empty' beaker† or an 'empty' bottle is held mouth-downwards in water, no water enters it (see Fig. 1). This shows that the vessel is not really empty and that there is some *material* inside the vessel keeping the water out, i.e. *air occupies space*.

If the 'empty' beaker is now turned mouth-upwards under water, bubbles* of air escape from the beaker as the water enters, because *air occupies space* and the water cannot get in until the air gets out.

The arrangement shown in Fig. 2 shows this even more clearly. The glass bottle (A) is fitted with a rubber cork carrying a narrow-stemmed glass funnel* and a bent glass tube which is connected to a rubber tube dipping under some water in a beaker (B). The rubber tube is pinched tightly between finger and thumb while the funnel is filled with water. No water enters the bottle until the rubber tube is opened, thus allowing air to escape from the bottle. As the water pours into the bottle (A), it *displaces** an equal volume of air, which can be seen escaping through the water in the beaker (B) as a stream of *bubbles*. (Notice how easy it is to *measure* the volume of some air and to *see* what this *invisible** gas is doing when we bring it under *control* by enclosing it *over water*. When we make *observations* in this way, *under controlled conditions*, we are carrying out an *experiment*, and it is by the *experimental method* that scientific facts and principles* are discovered and tested.)

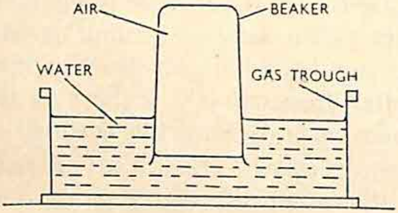


FIG. 1. Air occupies space.

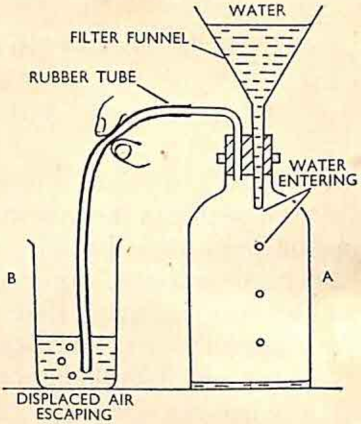


FIG. 2. Displacing air from 'empty' bottle.

These simple observations show clearly that *air occupies space*. What we usually call an 'empty' pint bottle really contains a pint of air, and when we fill the bottle with water from the tap this pint of *air* has to get out before we can put a pint of water in. Hence* it is quite reasonable to speak of pints or gallons or cubic* centimetres or cubic feet of air.

DOES AIR POSSESS WEIGHT?

Is it reasonable to speak of a pound of air, or of a ton of air? To answer this question we must find out whether we can actually *weigh* some air. To do this we must drive out the air from a suitable vessel, weigh the vessel, let in air once more, and then weigh it again to see if there is any gain in weight. Your teacher will show you how to do this, as follows:—A round-bottomed glass flask† is fitted with a tightly-fitting rubber cork through which passes a short glass tube ending in a piece of thick-walled rubber tube which can be closed with a screw-clip,* as shown in Fig. 3. A little water is put in the flask, the cork is replaced (with the screw-clip *open*), and the water is boiled over a small Bunsen†

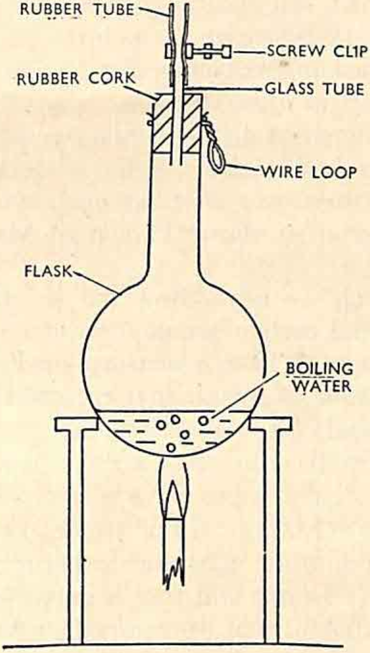


FIG. 3. Experiment to show that air has weight.

flame. When the water has been boiling for several minutes and the flask is quite full of steam (i.e. all the air has been driven out), the burner is taken away and the screw-clip is closed as quickly as possible. The flask is allowed to cool and is then weighed, hanging from the hook of the balance (see Fig. 102) by a loop* of wire. After the weight of the flask has been written down, the screw-clip is opened and we hear a hissing sound as the air rushes in. The flask is again weighed, full of air.

Weight of flask *before* opening clip = ...gm.
Weight of flask *after* opening clip = ...gm.
Therefore, weight of air in flask = ...gm.

It is clear that there is a distinct* *gain in weight*, so the experiment shows that *air has weight*.

Hence, *air is a substance that occupies space and possesses weight*. Every material substance known to Man has these two properties.

This air, of which we now know the weight, fills the space between the cork and the surface of the water in the flask. If we fill up the flask with water from a measuring-cylinder* (see Fig. 81) we can find the *volume* of the air that entered the flask when the screw-clip was opened.

Volume of air in flask = ...c.cm., hence.....c.cm. of air weigh.....gm.

Therefore, 1 litre† (1,000 c.cm.) of air weighs.....gm.

More careful and more accurate* experiments show that a litre of air weighs 1·3 gm., and that a cubic foot of air weighs 0·08 lb., or 1·28 oz. (A litre of water weighs 1,000 gm., so water is about 770 times heavier than air.)

Work out the weight of the air in a room which is 50 ft. long, 40 ft. wide, and 14 ft. high and write the answer here. ....
....

WHAT PART DOES AIR PLAY IN BURNING?

Everyday experience and observation teaches us (*a*) that when a fire is burning low, it can be made to burn up by blowing or fanning; (*b*) that it is very difficult to save a burning building when a strong wind is blowing; (*c*) that oil lamps have air-holes at the top and also at the bottom, just below the flame. Your teacher will set fire to some screwed-up paper in a sand-bath tray and then, when it burns brightly, cover the tray with an asbestos† sheet. What happens?......................................

Your teacher will also show you what happens when (*a*) dry sand, and (*b*) water, are poured over burning paper.These everyday examples show that the way in which a fire burns depends upon the supply of air and that we can put out a fire by keeping air away from the burning substance. To find out what really happens when things burn in air, we shall now study a convenient kind of fire—a candle* flame. It is difficult to find out what is really going on by merely watching a candle burning in the open, so we must carry out *experiments* in which the air supply is *controlled.*

WHAT DOES BURNING DO TO THE AIR?

Light a short piece of candle and, when it is burning steadily, invert* a clean, dry gas-jar over it.

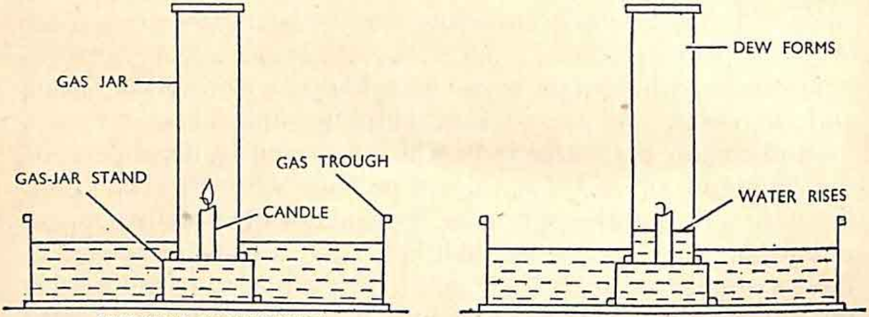
What happens?......................................

Raise the jar slightly, so that you can take out the candle. Light it again and, when it is burning steadily, invert the same jar over it once more, being careful while doing this not to disturb the air inside the jar.

What happens?......................................

Why did the candle flame go out? And why will the air that is left in the jar *not* allow a candle to burn in it? Perhaps something in the air has been used up by the flame? But our simple experiment does not *prove* this. To find if this is so, we must improve on our experiment and *measure* the volume of the air in the jar, before and after burning a candle in it. To do this, we shall invert a jar of air so that its mouth dips under water. Then, if a part of the air is used up by the burning candle, the water will rise in the jar.

Put your piece of candle on a wire stand in a trough* containing an inch or two of water (see Fig. 4). Light the candle and, when it is burning steadily, invert a clean, dry gas-jar over the burning candle.



BEGINNING OF EXPERIMENT

END OF EXPERIMENT

FIG. 4. Candle burning in air.

What happens?..

Repeat the experiment with jars of different sizes. In each case, what happens to

(i) The water-level inside the jar, *at first*?....................
(ii) The candle flame?.............................
(iii) The inner surface of the jar?......................
(iv) The water-level inside the jar, *finally**?..................

Repeat the experiment using (instead of the candle) wood (e.g. a match-stick), paper, kerosene† or paraffin† (on cotton-wool), and alcohol† (methylated spirit).†

What happens?..

....

We can now answer the following questions:—

Question	*Answer*
1. Why did the water-level in the jar fall slightly *at first*?	Because the candle flame warms the air in the jar, making it expand.*

Question	*Answer*
2. What is the dew* that forms on the inner surface of the jar?	It looks like tiny drops of water. Perhaps *steam* (water-vapour)* is formed when a candle burns? (We are not yet sure about this.)
3. Why did the candle flame go out after a time?	It seems that a flame cannot go on burning unless it has a free supply of air.
4. Why did the water rise in the jar at the end of the experiment?	Because part of the air in the jar is used up by the burning candle.

From these experiments, therefore, it seems that *air is made of at least two different gases, one of which is used up by the burning substance while the other is left behind unused.*

Like the early scientists, we shall call the first gas '*active air*', and the second gas, which remains unchanged, we shall call '*inactive air*'. Burning (or *combustion*†) seems to depend on the 'active air', hence this gas is said to *support combustion*, while the other gas, 'inactive air', *does not support combustion*.

WHAT HAPPENS TO THE ACTIVE AIR USED UP IN BURNING?

We have seen that 'active air' is used up in our experiments; but where has it gone? Unless it has been 'destroyed' in some way it must be still inside the jar at the end of the experiment (although perhaps in some other form). Now the only *new* substance that we can *see* at the end of the experiment is a little dew, which we think may be water. Perhaps something else has been formed that we cannot see—a gas? To find if this is so, we shall have to use a *test*, and make the invisible gas produce something that we can see.

Take a jar filled with fresh air, pour a little *lime-water*† into it, close the jar with a gas-jar cover, and shake.

What happens?.................................

Repeat this with a jar of air in which a candle has been burning. What happens? ....

This is a test for a gas which the early scientists called '*fixed air*'—formed whenever *fuels** burn in air. (Fuels are substances that we burn to produce *heat*, e.g. wood, coal, kerosene, and petrol,† and they all form 'fixed air' and water vapour when burnt. Lime-water is made by shaking up slaked lime† with water, allowing the mixture to stand, and then pouring off the clear liquid.)

WHAT ARE SCIENTIFIC TESTS?

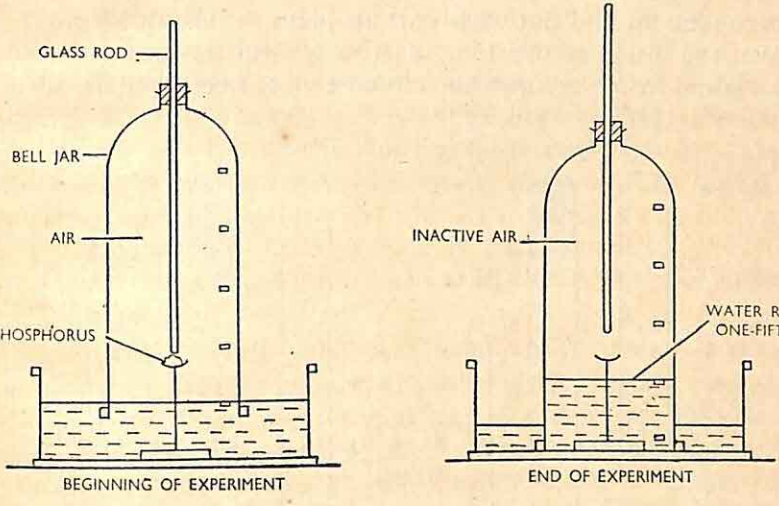
The use of *tests* needs some explanation. In our everyday life we depend upon our *senses** to know what is going on around us, i.e. by what we can *see*, *hear*, *feel*, *taste*, or *smell*. But in our work in science we often have to deal with things that we cannot 'sense'. We shall sometimes have to distinguish between several gases that have neither colour, taste, nor smell, and to do this we shall apply *chemical* tests*. For example, we cannot tell if 'fixed air' is present until we make it form something that we can *see*. (The clear lime-water turns 'chalky' or 'milky'.) We shall sometimes have to decide whether one substance is warmer than another when the difference is too small to distinguish by *feeling*, so we shall use a *thermometer** and *see* whether the mercury† in it expands or contracts.* The purpose of all our scientific tests is to produce something that we can *see*, *hear*, *feel*, *taste*, or *smell*. In most of our tests we *see* something happen, although in chemistry* we often make use of our sense of *smell*.

WHAT FRACTION OF THE AIR IS 'ACTIVE'?

When we burn fuels in air, 'active air' is used up, but we know that some 'fixed air' is formed in its place. Hence, although our candle experiments show that part of the air is used up in burning, we cannot tell from these experiments exactly what fraction* of the air is 'active'. To discover this, we must burn something that, in burning, does not form and leave behind another gas which will mix with the 'inactive air'. The only really suitable substance for this purpose is *phosphorus*† because when it burns it does not form a gas, but only a solid white ash which will dissolve readily in water.

WHAT HAPPENS WHEN PHOSPHORUS BURNS IN AIR?

(*Demonstration*)*. Your teacher will show you the following experiment: A metal stand is put in a trough containing a few inches of water, and a small piece of yellow phosphorus[1] is put on top of the stand. A glass bell-jar† is put over the phosphorus, as shown in Fig. 5, and the level of the water is marked on the side of the bell-jar. The phosphorus is then set on fire by touching it with the hot end of a glass rod that slides through the cork of the bell-jar. The phosphorus burns with a bright light and forms a thick cloud of white 'smoke'. After a short time, the phosphorus



BEGINNING OF EXPERIMENT

END OF EXPERIMENT

FIG. 5. Burning phosphorus in air.

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[1] *Yellow* phosphorus is a very dangerous substance, which catches fire of itself, without being brought near a flame, in a hot climate. It is stored and cut *under water*, and it must *never be touched with the fingers*. *Red* phosphorus is a safer and non-poisonous form of phosphorus used in making safety matches.

stops burning, and the water rises in the jar. The white 'smoke' gradually disappears as it dissolves in the water. If the level of the water is marked on the jar at the end of the experiment, it is found that *one-fifth* of the air has been used up by the burning phosphorus. If a drop of clear lime-water, on the end of a glass rod, is held inside the bell-jar, it remains clear, showing that there is no 'fixed air' in the jar. When a lighted wooden splinter* is put into the gas left behind in the bell-jar, the flame goes out at once.

We conclude,* therefore, that *air consists of one-fifth 'active air', which supports combustion, and four-fifths 'inactive air', which does not support combustion.*

WHAT HAPPENS WHEN IRON RUSTS?

We all know that when a piece of ordinary iron, e.g. an iron nail, is left in a damp place, it *rusts*. We shall now do some simple experiments to find out what part air plays in rusting.

Wet the inside of two long, narrow test-tubes† with water and push some *steel wool* into the closed end of one tube (A). Invert

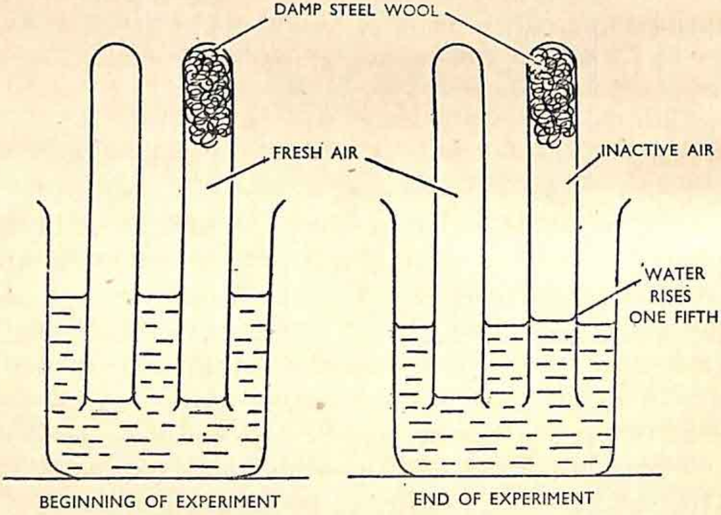

FIG. 6. Experiment to show that air is used up when iron rusts.

both tubes in water (as shown in Fig. 6), mark the levels of the water inside each tube by sliding rubber bands[1] over the tubes, and set aside your experiment until next science lesson. (The control tube (B), containing damp air but no steel wool, will show whether any rise in the water-level is due to air being dissolved by the water.)

What happens:

(*a*) to the iron (in the form of steel wool)? ....

(*b*) to the water-level in (A)? ....

(*c*) to the water-level in (B)? ....

Test the gas that remains in (A) with a drop of lime-water on the end of a glass rod.

What happens? ....

What does this show? ....

Test with a lighted wooden splinter the gas that remains in (A).

What happens? ....

What does this show? ....

We see, then, that *when iron rusts, one-fifth of the air is used up*. This result reminds us of our demonstration experiment of burning phosphorus in air. It seems that *rusting is a very similar kind of change to burning or combustion, which the remaining four-fifths of the air will not support.*

WHAT HAPPENS TO THE ACTIVE AIR USED UP BY BURNING PHOSPHORUS AND RUSTING IRON?

In our experiments on burning fuels, part of the air in the jar disappeared, and also a small quantity of the burning substance. The only new substances formed were (*a*) 'dew' on the sides of the jar, and (*b*) 'fixed air'. In the 'bell-jar experiment', the only new substance formed was white phosphorus ash. In the same way, in the experiment on the rusting of iron, the only new substance formed was iron rust. Perhaps the iron rust and the phosphorus ash contain the 'active air' that disappeared during the experiment? But, if *iron rust* $=$ *iron* $+$ *active air*, then the rust should weigh *more* than the original clean iron. And, in the same way, if *phosphorus ash = phosphorus + active air*, then the ash should weigh *more* than the original unburnt phosphorus. We can test this by experiment.

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[1] Cut off from rubber-tube with scissors.

IS THERE ANY CHANGE IN WEIGHT WHEN IRON RUSTS?

Take a 10-in. strip of thin iron (e.g. the ½-in. wide material used for banding packing-cases) and clean it thoroughly with sand-paper. Bend it at its mid-point, as shown in Fig. 7, and hang it from a loop of wire. Shorten the heavier end until the two sides balance.[1] Then rub one half of the iron with an oily cloth and wet the other half with water. Repeat this wetting of half the iron each day until this part of the iron is covered with rust. Then allow it to dry. What happens? ....

....

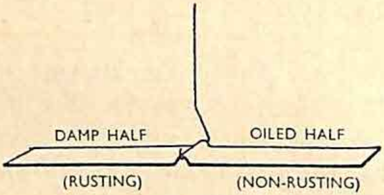

FIG. 7. Experiment to show that iron gains weight in rusting.

Hence, *there is a gain in weight when iron rusts*, so it seems that *the iron has taken up (or combined* with) the active fifth part of the air to form iron rust*. It is possible, however, that part of the increase in weight is due to the iron combining with the water used for keeping the iron damp. So your teacher will show you a demonstration experiment, using phosphorus, in which only *dry* air is used.

IS THERE ANY CHANGE IN WEIGHT WHEN PHOSPHORUS BURNS?

It is clear that we shall have to burn a weighed quantity of phosphorus in dry air, catch all the ash that is formed, and then weigh it. This can be done by using the apparatus shown in Fig. 8. The drying-tube 'A' contains *fused* calcium chloride*† to dry the air as it enters the apparatus. The right-hand end of the glass tube 'B' is loosely packed with asbestos wool for a length of at least 2 in., to trap the ash from the burning phosphorus, so that it can be weighed at the end of the experiment. About 1 gm. of *red* phosphorus (which has been dried in a *desiccator*†) is put in the middle of tube 'B', and a little asbestos wool is put near the left-hand end of the tube. This tube 'B', containing the *unburnt* phosphorus, is weighed before the experiment. The tubes 'A' and 'B' are then joined together as shown in the diagram, and the other end of 'B' is connected to a filter-pump† (or some other arrangement for drawing a gentle stream of air through the apparatus). The phosphorus in 'B' is then set on fire by heating the tube with a small flame, and the white ash from the burning phosphorus is caught by the asbestos wool. When most of the phosphorus has burnt away, the stream of air is stopped and the tube 'B' is allowed to cool. When it is cool, the tube 'B', which now contains phosphorus ash, is again weighed. The drying-tube 'A' is necessary because phosphorus ash has a great attraction for water and would take up water from ordinary damp air. This would spoil the experiment since we want to compare the weight of the *dry* unburnt phosphorus with the weight of *dry* phosphorus ash.

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[1] Use an old pair of strong scissors or, better, a pair of sheet-metal cutting-shears.*

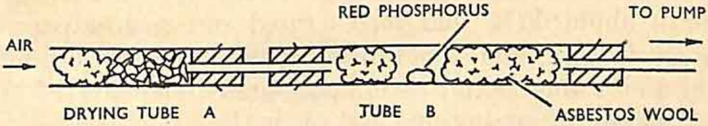

FIG. 8. Burning phosphorus in dry air.

Weight of tube + asbestos wool + *unburnt phosphorus*
= . . . . .gm.

Weight of tube + asbestos wool + *phosphorus ash*
= . . . . .gm.

Hence, *the phosphorus ash weighs more than the original, unburnt phosphorus.*

This gain in weight can only have come from the air. But we have seen that one-fifth of the air disappears when phosphorus is burnt under a bell-jar, so we can now explain what has happened to this 'active air'.

The 'active air' combines with phosphorus to form phosphorus ash, just as iron combines with 'active air' to form iron rust.

These experiments on the rusting of iron and the burning of phosphorus are very important, because they show that when substances burn or rust they *combine with* part of the air. It was not until about 1772 that men carried out such experiments (*using the balance*) and began to understand the true meaning of *burning* and *rusting*. Before then, they believed that substances *lost* some material during burning and rusting!

WHAT CAN WE CONCLUDE FROM OUR EARLIER EXPERIMENTS?

Our experiments prove that air consists of at least two gases, one of which (active air) is able to combine with iron, phosphorus, and other substances, while the other gas (inactive air) will not combine with these substances. About one-fifth of the air is 'active' and the remaining four-fifths is 'inactive'. The work we have done so far provides a good example of *the scientific method* and starts your training in *scientific thinking*. This is one of the main reasons why you are studying science; because the *method of science* can be used in your daily life. Much of the trouble in the world arises because many people do not think scientifically. They believe anything that they are told and anything that they read, without *inquiring* into these statements and *testing* their truth.

DO ANY OTHER METALS RUST?

(i) Hold a piece of *magnesium*† wire or 'ribbon' [1] in the crucible† tongs† and heat one end in the Bunsen flame.

What happens?..

---

[1] Magnesium ribbon is simply flattened magnesium wire.

What is left? ....

(ii) Hold a piece of thin *copper* sheet in the crucible tongs and heat it red-hot in the Bunsen flame (but do not let it melt). Then remove the copper from the flame and allow it to cool.

What do you notice? ....

These experiments show that *some metals which rust only very slowly at the ordinary temperature will rust rapidly if they are heated*. You will always find that chemical action is made more rapid by heating. This is why you see so many burners in a laboratory*: many of the changes that we carry out in a few minutes by heating would take *years* to complete at lower temperatures.

IS THERE ANY CHANGE IN WEIGHT WHEN MAGNESIUM BURNS?

Take a porcelain* crucible and lid, and heat them in a clean, non-luminous* Bunsen flame, supported on a fireclay† triangle,* for a few minutes. Then take away the burner and wait until the crucible and its lid are cool enough to touch with the finger-tips. You will be given about 20 cm. of magnesium ribbon, which you must clean by drawing it through a folded bit of sand-paper. When the crucible is cool, put the magnesium into it, broken up into short pieces. Then weigh the crucible with its lid and the magnesium, entering the weight below. Put the crucible on a fire-clay triangle and heat it with a clean, non-luminous flame, gently at first, and then strongly. After heating strongly for at least five minutes, lift the crucible-lid with crucible-tongs, *very cautiously*, so as to let in a little more air, but take great care that no ash escapes. When you see no more bright flashes of light inside the crucible, remove the lid altogether (putting it on the asbestos sheet) and heat the crucible as strongly as possible. After you can see no further change, let the crucible and its contents cool and then weigh them.

Weight of crucible lid + *magnesium* = ...gm.
Weight of crucible lid + *magnesium ash* = ...gm.

Hence, the *magnesium ash weighs*.........*gm.* ....*than the original*, *unburnt magnesium*, showing that *magnesium, when it* *burns, combines with part of the air*, just like burning phosphorus, or rusting iron.

UNDER WHAT CONDITIONS DOES IRON RUST?

We know from our everyday experience that iron rusts in damp air (i.e. air + water). We shall now try to find out *whether both air and water are necessary*, or whether *air alone* (i.e. dry air) or *water alone* (i.e. 'air-free' water) will make iron rust.

WILL IRON RUST IN DRY AIR?

Take an iron nail and rub it with sand-paper until it is quite clean and free from rust. Put the nail in a desiccator and leave it there for several days. Then examine the nail.

What do you notice? ....

Your teacher may be able to show you some iron nails that have been kept in a desiccator *for several years*.

Are they rusty? ....

Hence, *air alone, without water, will not make iron rust.*

WILL IRON RUST IN WATER THAT CONTAINS NO AIR?

Half fill a test-tube with water and boil it for several minutes to remove all the dissolved air. Then stop heating and put a few clean iron nails into the hot water. Drop some oil or a small lump of vaseline† (petroleum jelly†) on the surface of the water so as to form an air-tight covering, as shown in Fig. 9. After about a week, examine these iron nails.

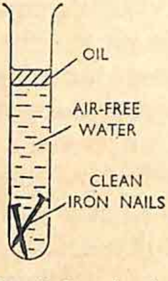

FIG. 9. Iron in air-free water.

What do you notice? ....

....

....

Your teacher may be able to show you some iron nails that have been kept in air-free water *for several years*. Are they rusty? ....

....

Hence, *water alone, without air, will not make iron rust. Iron will rust only if both air and water are present.*

Although iron is the commonest *metal* in everyday use, it has one very serious disadvantage—*it rusts*. It has been calculated that it costs at least 2,000 million pounds every year to replace all the iron and steel articles in the world that have been spoilt by rusting. It is clear that rusting can be stopped by keeping air away from the surface of the iron, and there are many practical ways of doing this. The simplest method is to rub oil or grease over the iron, but the thin layer of oil is easily rubbed off, and then rusting begins. The commonest method of protecting iron is by painting. When the paint 'dries', it forms a tough skin that keeps air away from the iron. Another common and lasting protection against rusting is a thin layer of some other metal that does not rust so easily, e.g. iron sheets are dipped in melted tin to make *tin-plate*, which does not rust until the tin is scratched and the iron is exposed* to the air. *Galvanized iron*† is made by dipping iron into melted zinc.† Iron is also coated with nickel† and chromium† by *electro-plating*,† which we shall learn about in Book Four.

WHAT IS THE ATMOSPHERE MADE OF?

The *atmosphere*† is a layer of air, many miles thick, which surrounds the Earth. Our earlier experiments have shown that air is a mixture of gases and that about one-fifth of its volume is '*active air*' (which supports combustion) and about four-fifths is '*inactive air*' (which does not support combustion). We shall now give the gases their modern chemical names and mention some other gases that are present in the atmosphere in smaller amounts.

'Active air' is now called *oxygen*† and the more accurate proportion* of oxygen in the air is 21 per cent. 'Inactive air' makes up 79 per cent. of the air, 78 per cent. being *nitrogen*† while the other 1 per cent. consists of the '*rare gases*' which are quite inactive and do not combine chemically with any other substances. Besides these gases, air always contains a very small quantity of '*fixed air*' (0·03 per cent.) which has the chemical name *carbon dioxide*.†

The air also contains some *water-vapour*, but the proportion varies* very greatly, e.g. in the wet tropics the air contains much water-vapour, while the air over the Sahara Desert sometimes contains very little. The atmosphere also contains tiny particles* of solid matter, or *dust*, but the amount of dust in the air varies from place to place and from time to time.

The approximate composition of dry air, by volume, is shown in the following table and also in Fig. 10.

Active air	Oxygen	21%
Inactive air	Nitrogen	78%
	Rare gases	1%
Fixed air	Carbon dioxide	0·03%

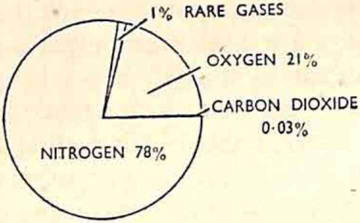

FIG. 10. Composition of dry air by volume.

Everyone knows that air is essential* for life. It is the *oxygen* in the air that enables animals and plants to live in it, and without oxygen all living things would die. Oxygen is also necessary for *burning*, *rusting*, and *decay*. We shall learn more about this most important gas later.

The *nitrogen* in the air takes no active part in breathing, burning, rusting or decay. In later lessons we shall learn that although the nitrogen in the air is so inactive, when it is combined with other substances it is extremely important, since it forms an essential constituent* of the food materials of animals and plants, and it enters into the composition of all living matter.

The air contains five '*rare gases*', but they are so inactive that it would make little difference to the air if they were not present at all. Although they are called 'rare' gases, one of them—*argon*† —is present in the air to the extent* of 0·9 per cent. (i.e. about 9,000 parts per million: 30 times more plentiful in air than carbon dioxide). Argon is used, mixed with nitrogen, in 'gas-filled' electric light bulbs.* *Neon*† (which forms only 0·0015 per cent. of the air, or 15 parts per million) is used for filling the bright red 'neon lights' used for electric advertising signs. *Helium*† (which is present to the extent of only 0·0005 per cent., or 5 parts per million) is the most suitable gas for filling airships and balloons* since although it is very 'light', it will not burn. Although there are other sources of helium, it is still too rare and expensive for general use in airships and balloons. (*Hydrogen*,† the gas which is generally used for this purpose, is even 'lighter' than helium, but it has the great disadvantage that it catches fire very readily.) The other two 'rare gases', *krypton*† and *xenon*†, are present in the air in even smaller proportions than helium.

If some clear lime-water is put in a watch-glass and exposed to the air for several hours it turns 'chalky', showing the presence of 'fixed air' or *carbon dioxide*. Although the proportion of carbon dioxide in air is so small (only 0·03 per cent. or about 300 parts per million parts of fresh air) it is extremely important since *green plants in sunlight* take in carbon dioxide from the air and use it for building-up substances like *sugar* and *starch*† which form part of the food of plants (and, also, of animals). We shall study this important gas in detail later.

We have all seen that the outside of a glass filled with ice-water very quickly becomes covered with drops of a clear liquid. This is because *water-vapour* from the air has *condensed** on the cold surface. We shall discuss the everyday importance of the amount of water-vapour in the air in Book Three.

There is always some *dust* in ordinary air. This dust consists of particles of solid matter which are so small that they float in the air. When seen under the microscope,* dust is found to contain material from many different sources, e.g. unburnt carbon (soot†) from fires; bits of cotton and wool from clothing; bits of animal hair and skin; rock-dust and very fine sand, stirred up by the feet of animals and by the wheels of cars and carts, or carried by the wind from bare patches* of earth.

Besides these non-living particles, air always contains '*living dust*'. These living particles are mainly *bacteria*† and the *spores*† *of moulds*.* These spores are small enough to float about in the air until they reach a suitable place to grow. Bacteria are still smaller (often less than 0·001 mm. in length), but in spite of their small size they are very important in everyday life. Some kinds of bacteria cause certain diseases, but most of them are harmless and even useful. We shall learn more about this 'living dust' later.

CHAPTER II

MATTER: ITS CLASSIFICATION AND ITS CHANGES

Matter means any kind of material that has weight and which occupies space; that is, *all matter has weight and volume*. There are in the world so many hundreds of thousands of different materials, or *substances*, that it is useless to try and study them without some *system* for sorting out the different kinds of matter and *classifying* similar substances together in groups; just as the books in a library must be classified if you are to find the books you want without waste of time. In a library, it is possible to classify the books in various ways. For example, we could put on the same shelf all the books of the same *size*, or all the books with covers of the same *colour*; but although these arrangements might be very nice to *look* at, they would be useless to anyone that had to *use* the library. In practice, it is much more convenient to group the books according to their *contents*, putting all the books of adventure, all the books of travel, all the historical books, and all the scientific books on separate shelves. Then you know just where to look for any particular *kind* of book.

When we group together things that are alike, we can talk about them more easily if we have a *name* for each group of things. Scientists found out long ago that they could not talk to one another about what they had learned, and they could not explain what they had discovered, unless they had *exact names* for things. In this science course, therefore, when learning new scientific names [1] you must also learn their exact meaning.

To classify everything in the world into convenient groups is

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[1] These are marked † at their first appearance in these text-books and also in the Index.

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much more difficult than classifying the books in a library. In fact, it took the early men of science over a thousand years to work out a suitable system for the *classification* of matter*. Many different systems were tried, but it was not until about the end of the eighteenth century that a simple and satisfactory *chemical classification* was made. By that time it had been discovered by experiment that certain substances could not be split up or *decomposed** into two or more different substances, by any means known at that time. *These simple substances were called chemical elements:*† substances that had not yet been split up into two or more simpler substances by ordinary chemical methods. A more modern definition* of an element is given on p. 32.

Although there are hundreds of thousands of different substances in the world, when they are all split up into their simplest constituents, the total number of different elements now definitely known is only 96. It is clearly a great help to scientific classification that there should be so few elementary substances in the world, and the modern system of the *chemical classification of matter* is based on the elements that each substance contains, and the way in which these elements are built up into different substances. Of these 96 elements, a large proportion of them are not present in common materials, and we shall mention only about 30 of them in this science course. About 98 per cent. of the Earth's crust* (including the air and the sea), to a depth of 10 miles, is made up by only about a dozen elements: the remaining 84 elements together make up only about 2 per cent. The approximate* proportions (by weight) of the commonest elements in the Earth's crust are:—

OXYGEN	47%	CALCIUM†	4%	TITANIUM†	0·6%	PHOSPHORUS	0·1%
SILICON†	28%	SODIUM†	3%	CARBON	0·1%	BARIUM†	0·05%
ALUMINIUM†	8%	POTASSIUM†	3%	HYDROGEN	0·1%	CHLORINE†	0·05%
IRON	5%	MAGNESIUM	2%	MANGANESE†	0·1%	SULPHUR†	0·05%

Nearly half the Earth's crust, therefore, consists of oxygen. About half of the remainder is *silicon*, an element that you will seldom see free and uncombined, but which you often see combined with oxygen as *silica*† (or silicon dioxide†), the main constituent of ordinary *sand*. *Clay*, another very common material, also contains silicon and oxygen combined with *aluminium*, which is the next commonest element.

Examine the following elements, most of which are solids at room temperature. Some of them you can handle, but some of them are so *active* that your teacher will merely show them to you, demonstrating some of their properties.

ALUMINIUM
IRON
COPPER
ZINC
MAGNESIUM
CALCIUM
LEAD†
TIN
POTASSIUM
SODIUM
MERCURY
IODINE†
PHOSPHORUS
CARBON
SILICON
SULPHUR
PLATINUM†
SILVER
CHROMIUM
NICKEL

Underline the *metals* in the above list and write short descriptions of all these elements (about two or three lines) mentioning only the more striking properties in each case, e.g. 'Aluminium is a light, silver-coloured metal used largely for cooking-vessels and for aeroplane parts.'

WHAT IS MEANT BY THE THREE STATES OF MATTER?

Another simple method of classifying materials is to divide them into *solids*, *liquids*, and *gases*. For example, at room temperature, iron is a solid, water is a liquid and air is a gas. It is important to be clear about the characteristics of these *three states of matter*.

A solid has a definite shape and size* (or *volume*) and force is required to change this *shape* (although force will seldom change the *volume* of a solid). Some of the hardest work in the world is done in changing the shape of solids, e.g.* all wood-work and metal-work, digging earth, and breaking rocks. This resistance to change of shape is sometimes expressed by saying that *solids are rigid.**

A liquid has a definite size (or volume) but it has no definite shape. There is no difficulty in changing the *shape* of a liquid. For example, if we pour water from a square pint bottle into a round pint bottle the water immediately *takes the shape of the containing vessel* (a very different business from trying to force an iron rod, 1 inch square, into a round hole of 1 square inch cross-section* in a block of iron). The size, or volume, of the liquid, however, is unchanged and we cannot compress* more than a pint of water into a pint bottle. When a liquid does not completely fill the containing vessel its upper surface is horizontal.

A gas (or vapour) has neither definite shape nor size—it immediately takes the shape of any vessel into which it is put, and always completely fills the vessel. Thus, if we take a large vessel from which all the air has been removed, and let into it a little air, this quantity of air, however small, will immediately expand to fill the vessel. On the other hand, we can take a vessel that is already 'full' of air and, by using a bicycle pump, we can force in twice as much air. That is to say, air (like all other *gases*) has no fixed volume and can be either compressed or made to expand.

There are many important everyday applications of these different properties of solids, liquids and gases. When an article of complicated shape has to be made of iron, it is very much easier to pour *liquid iron* into a mould* of sand of the required shape, than to cut or file the article from a block of *solid iron*. In the same way, liquid concrete† is poured into wooden moulds and then allowed to become solid in shapes that would be very difficult to cut from solid rock. Damp clay, too, is easily shaped into bricks which become rigid solids after heating. '*Plastics*'* (e.g. 'Bakelite'† and 'Perspex'†) make use of the same principle of changing the shape of the material while it is in the liquid state.

WHAT IS MEANT BY CHANGE OF STATE?

When solid ice is heated it melts to form liquid water, and when water is boiled it becomes a gas—steam.

Although *ice*, *water*, and *steam* have special names, they are only different forms, or *states*, of the same substance—*water*. *Ice* is *solid water*; and *steam* is *gaseous water*. When ice melts to form water, therefore, it is only a *change of state*. Such changes of state are called *physical* changes* because they are studied in more detail in the branch of science called *Physics** than in the branch of science called *Chemistry*.

A physical change is one in which no new substance is formed.

Only the physical state changes and the change is usually *easy to reverse*,* e.g. water can be changed into steam by heating, while steam can be changed back to water again by cooling. There is *no change in weight* during a physical change, e.g. 100 gm. of water will give 100 gm. of steam when boiled or 100 gm. of ice when frozen. Except in the case of water (where we have different names for the different states—ice, water, steam) we keep the same name for all three states, e.g. solid *air*, liquid *air*, and *air* (the gas); solid *sulphur*, liquid *sulphur*, and *sulphur* vapour; thus showing that *there is no change of substance.*

WHAT IS A CHEMICAL CHANGE?

When magnesium burns in air, two substances—magnesium, a solid metal, and oxygen, a colourless gas—*combine* together to form a third substance—white magnesium ash: heat and light being produced during the *reaction.** The magnesium ash is clearly *an entirely new substance*. It weighs more than the original magnesium and it is impossible to get back metallic magnesium from the white ash without using some other substance to remove the oxygen *by chemical action*. Such a *change of substance* is called a *chemical change*.

A chemical change is one in which new substances are formed, with entirely different properties.

You will find, however, that in most of your chemical experiments you are using physical means to produce and control chemical changes, e.g. *mixing* substances together, *heating* substances, passing *electric currents* through substances. We shall refer later to this close relationship between *chemistry* and *physics*.

HOW TO EXAMINE SOME PHYSICAL AND CHEMICAL CHANGES

(1) Take a piece of nichrome† wire (a mixture of iron, nickel, and chromium), roll it into a spiral* coil,* and weigh it. (........gm.) Hold it with crucible tongs in the hottest part of the Bunsen flame. What happens?........................

Remove the nichrome wire from the flame and let it cool. Weigh it again (........gm.). Compare its appearance with that of some nichrome wire which has not been heated. Can you see any difference?..

What kind of change does nichrome wire undergo when heated? .... Why do you say this?..........

....

(ii) Hold a piece of magnesium wire with crucible tongs in the edge of the Bunsen flame. What happens?..................

....

Is there any change in weight? (See p. 15)........ What kind of change is this?..................................

Why do you say this?..............................

....

(iii) Heat a little paraffin wax† *very gently*, holding the test-tube about $\frac{1}{2}$ in. above a *small* flame. What happens?..............

....

Pour the hot wax into some cold water in an evaporating dish.†
What happens?..................................
Compare the final product with the original wax ....

....

What kind of changes are these?...................
Why do you say this?..............................

....

(iv) (*a*) Heat a little red mercuric oxide† (mercury rust—*Poison*) in a small, dry test-tube, heating only *gently*. What is the first change you see?.............................

....

Allow the tube to cool again. What happens?...............

....

What kind of change did the mercuric oxide undergo when heated *gently*?....................... Why do you say this?

....

(*b*) Now heat the mercuric oxide very strongly, putting a glowing* (red-hot) wooden splinter in the mouth of the tube from

time to time. What happens to the glowing splinter?. . . . .
. . . . What happens to the mercuric oxide? . . . .

When there is no further change, stop heating and allow the tube to cool. What do you notice when you examine the tube?. . . .
. . . .

What kind of change does mercuric oxide undergo when heated *strongly*?. . . . . Why do you say this?
. . . .
. . . .

(v) Take a piece of 'soft' iron (e.g. an iron nail) and hold it over a few iron filings.* Will it pick up the filings?. . . . . Now put the 'soft' iron on the end of a bar-magnet† and hold it over the filings. What happens?. . . . .

Why?. . . . .

Will the soft iron still pick up iron filings after the bar-magnet is removed?. . . . . Why?. . . . .

What kind of change has the iron undergone? . . . .
. . . . Why do you say this?. . . . .
. . . .

(vi) Put a small lump of freshly-burnt *quick-lime*† in an evaporating dish. Add water to it, *drop by drop*, until there is no further change. What do you see?. . . . .
. . . .

What kind of change is this?. . . . .

Why do you say this?. . . . .
. . . .

(vii) Close the end of a bicycle pump tightly with the left forefinger and then push in the handle of the pump. What happens to the air inside the pump?. . . . .
Now let go the handle. What happens?. . . . .
. . . . Why?. . . . .
. . . .

What kind of changes did the air in the pump undergo?. . . . .
. . . .

Why do you say this?..............................
....

(viii) Put about 10 c.cm. of blue copper sulphate† solution* in a test-tube (three inches in a five-eighths inch test-tube) and then add a small, *clean*, iron nail. What happens (*a*) at first?............
.... (*b*) after a long time?..
....

What kind of change is this?.......................
Why do you say this?..............................
....

(ix) Put a *small* quantity of ammonium chloride† in a clean, *dry* test-tube and heat it gently over a small flame. What happens?
....

Stop heating when there is no further change at the bottom of the tube and allow it to cool. What happens?.................
.... What kind of change has the ammonium chloride undergone?...................
Why do you say this?..............................
....

(x) (*a*) Put a little sugar on a crucible lid (or on a piece of broken porcelain) and heat it *very gently*. What happens?............
....

Allow it to cool. What happens?.......................
.... What is the taste of the substance?.........
.... What kind of change did the sugar undergo when heated *gently*?..................... Why do you say this?...
....

(*b*) Now heat the sugar *strongly*. What happens? ....
....

What kind of change does sugar undergo when heated *strongly*?
....

Why do you say this?..............................
....

(xi) Make a shallow hole near one end of a piece of charcoal† and put into it a little lead oxide† (or litharge†). Heat the lead oxide strongly with a mouth-*blowpipe*. (Your teacher will show you how to do this.) What happens?..............................

....

What kind of change takes place when lead oxide is strongly heated in contact* with charcoal?....................

Why do you say this?..............................

....

WHAT DO WE MEAN BY THE PHYSICAL AND CHEMICAL PROPERTIES OF MATTER?

For convenience, the scientific study of the properties of matter is usually divided into two branches—*Physics* and *Chemistry*. In this General Science Course there is no need to separate completely these two closely related subjects (in any case, you cannot go very far in 'chemistry' without knowing some 'physics'); but as we shall often use the terms *physical* and *chemical* it is important to know what these terms mean.

Physics is the study of the effect of different forms of energy† on matter.

The scientific meaning of 'energy' will be explained more fully in Book Four. For the present it is enough to remember that *heat*, *light*, *sound*, *electricity*, and *movement* are all *forms of energy*, and that they all make things happen to matter. We say that a dynamo† is a source of electrical energy; a loud-speaker† is a source of sound energy; a coiled-up clock-spring is a source of energy of movement; burning wood is a source of heat energy; the Sun is a source of light energy and heat energy; and so on.

Physics deals with the effects of these different forms of energy upon matter, but only so far as they change the *properties* of materials *without changing their chemical composition*, i.e. without producing entirely new substances.

Chemistry also deals with changes in matter; but during *chemical* *changes* substances change not only their properties but also their *chemical composition*, and entirely new materials are produced.

In this science course you will soon realize the importance of *accurate description*, and in describing the properties of any material it is convenient to group its properties, or characteristics, into two classes:—(i) its *physical properties*; (ii) its *chemical properties*.

We recognize things in various ways, e.g. by *looking* at them to see their *colour*, *shape*, and *size*; by *lifting* them to feel their *weight*; by *feeling* their surface; and sometimes by *smelling* and even *tasting* them.

In describing the *physical properties* of a substance we state (*a*) whether it is a solid, a liquid, or a gas at the ordinary temperature; (*b*) its colour; (*c*) its taste (if any); (*d*) its smell (if any); (*e*) its *density*† (that is to say, in the case of a solid or a liquid, whether it is 'heavier' or 'lighter' than water; or in the case of a gas, whether it is 'heavier' or 'lighter' than air);[1] (*f*) whether it dissolves in water; (*g*) its melting-point (i.e. the temperature at which a solid melts) and its boiling-point (i.e. the temperature at which a liquid boils).

In the case of a solid we say whether it is hard or soft, and if it is a gas we also say whether it is easily changed to a liquid.

The *chemical properties* of a substance are those that describe what it does (and what it does *not* do) when it reacts* with other substances, in Nature and in the laboratory, that is to say, the chemical changes which it undergoes to produce entirely new substances of different composition. For example, we state:

(*a*) whether it burns in air; (*b*) whether it allows other things to burn in it (if the substance is a gas); (*c*) whether it splits up when heated and, if so, what substances are formed; (*d*) how it reacts with other substances.

By always following this plan we shall be able to give clear and accurate descriptions of all the materials we study.

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[1] You will learn about *density* in Chap. VI.

As an example, let us describe the properties of air (as far as we can with our present knowledge):—

Air is a gas without colour, taste, or smell. It dissolves slightly in water. It does not burn, but it allows things to burn in it (i.e. it supports combustion). It is not decomposed by heat. It has no immediate action on lime-water.

To take another example:—Mercuric oxide is a red powder with no smell. (As it is poisonous we do not attempt to describe its taste.) It is very 'heavy' (or *dense*) and it does not dissolve in water. When heated, it first turns black and then decomposes into mercury and oxygen.

Describe the following materials on the same plan:—Water; magnesium; petrol; iron; quick-lime; paraffin-wax; yellow phosphorus; sugar; glass; rubber; cork.

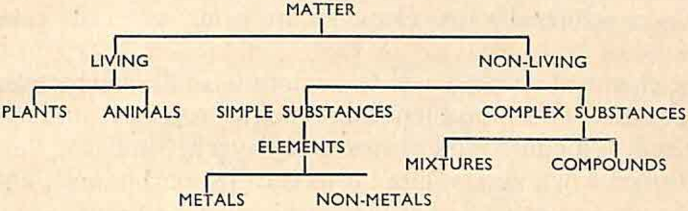

FIG. 11. The classification of matter.

HOW ARE COMPLEX MATERIALS CLASSIFIED?

One way of classifying all the materials in the world is to distinguish between (*a*) the materials that are chemically *simple*, and (*b*) the materials that are chemically *complex*,* i.e. between substances consisting of *only one kind of matter* and those consisting of *two or more different kinds of matter*. Out of all the hundreds of thousands of different substances in the world, there are only 96 that have never been split up into simpler substances by ordinary chemical means, hence our group of *chemically simple substances* is limited to the *elements*, and we have seen that only a few of these are met with, free and uncombined, in everyday life.

Most everyday materials are complex and contain several elements, and these complex materials are classified into groups of materials with similar properties. The two main groups of *complex materials* are (*a*) *mixtures* and (*b*) *compounds*.† Although there is not much difference between the everyday meanings of these two words, there is an important distinction between their scientific meanings.

Two substances can be put together in two different ways:

(*a*) They may form a *mixture* in which both substances are present *with their original properties unchanged*. For example, air is a *mixture* of oxygen and nitrogen.

Or (*b*) they may *combine together* and undergo a *chemical change* to form an entirely new substance in which *the original substances do not keep their original properties*. For example, iron rust is *not a mixture* of iron and oxygen, for it shows none of the properties of either iron or oxygen: it is a *compound* of iron and oxygen in which the two elements are *held together by chemical attraction*.

The chemical names given to compounds tell us what elements they contain. Thus, the chemical name for iron rust is *iron oxide*†, because it is a compound of iron and oxygen. Similarly, the white ash formed when magnesium burns is called *magnesium oxide*.†

Mixtures are composed of two or more substances that are NOT held together by chemical attraction: the properties of mixtures vary according to the proportions of their constituents.

Chemical compounds consist of two or more elements that are bound together by chemical attraction: their properties are definite, and the relative proportions of their constituents are fixed.*

Now that we have defined *compounds* we can give a better definition of elements:

Elements are substances that increase in weight in all the chemical changes in which they take part. In such changes elements combine with other substances. If a substance decreases in weight during a chemical change then it must be a compound, not an element.

Hence the three main groups in the *chemical classification of matter* are *elements*, *mixtures*, and *compounds*.

There are so many thousands of chemical *compounds* that it is necessary to classify them into further groups, each group consisting of compounds of similar chemical composition and with similar properties. You will learn about the various classes of chemical compounds later.

A chemical compound is the result of a chemical change; and in order to separate a compound into its constituents it is necessary to overcome the chemical attraction that is holding the constituents together. The constituents of a mixture, on the other hand, are not bound together by chemical attraction and they can therefore be separated by *physical* means, without using a chemical reaction. The following example will illustrate the differences between the properties of mixtures and compounds.

HOW TO COMPARE THE PROPERTIES OF A MIXTURE OF IRON AND SULPHUR WITH THOSE OF A COMPOUND OF IRON AND SULPHUR

(i) Examine the properties of the element iron:—

Take some iron filings. What is their colour?...............
Hold a magnet over the iron. What happens?................

....

(ii) Examine the properties of the element sulphur:—

Take some powdered sulphur. What is its colour?...........
Put a *very small quantity* of sulphur in a dry test-tube and add about 2 c.cm. ($\frac{1}{2}$ in. in a $\frac{5}{8}$-in. test-tube) of *carbon disulphide.*[1]†
What happens?...

(iii) Examine the properties of a *mixture* of iron and sulphur:—

Thoroughly mix together equal volumes of iron filings and powdered sulphur in a mortar.† What is the colour of the mixture?
.... What can you see with a lens*?..............
.... What happens when you hold a magnet over the mixture?..............................

....

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[1] Never take carbon disulphide near a flame as it catches fire very readily. If you have to warm carbon disulphide, hold the vessel containing it in hot water and NOT over a flame. Do not breathe more of the harmful vapour than you can help.

West Bengal

Put a little of the mixture into a test-tube half-filled with water. Shake thoroughly, and then allow to stand for a while. What settles first?............. Last?..............

Put a little of the mixture on a *dry* filter-paper, in a filter-funnel*; place a clean, dry watch-glass underneath, and then pour about 2 c.cm. of carbon disulphide on the mixture. What happens?....
....

This shows how *the constituents of a mixture keep their own original properties unchanged*, and also how *the constituents of a mixture can be separated by simple, physical means.*

(iv) Examine the properties of a *compound* of iron and sulphur:

Put the rest of your mixture of iron and sulphur in an old test-tube and lay it horizontally over a wire gauze* supported on a tripod* stand. Put your burner under the closed end of the tube and watch carefully what happens. Remove the burner as soon as you see a striking change. What happens?...................

What is left? ....

Remove the residue* from the test-tube (it may be necessary to break the tube in order to do this), and hold it in the flame with crucible tongs. Is there any further change?.................

Allow the solid lump to cool and then hold a magnet over it. What happens?.......................................

Crush up the lump in a mortar and then examine the compound of iron and sulphur—*iron sulphide*†—with a lens. Can you see any grey iron?........ Or any yellow sulphur?.......

Put a small quantity of the compound in a dry test-tube and add about 2 c.cm. of carbon disulphide. Warm the tube in hot water and shake gently; then filter through a dry filter-paper on to a clean watch-glass.

Does the carbon disulphide remove any sulphur from the compound? ....

This shows how *the properties of a compound are quite different from those of its constituents*, and how *the constituents of a compound (being held together by chemical attraction) cannot be separated by simple, physical means.*

WHAT ARE THE DIFFERENCES BETWEEN MIXTURES AND COMPOUNDS?

We can now summarize* the important differences between mixtures and compounds.

MIXTURES	COMPOUNDS
1. *The constituents of a mixture may be mixed together in any proportions, i.e. the composition of different mixtures of the same constituents may vary.*	*The constituents of a compound are always present in fixed and definite amounts, i.e. different samples of the same compound always have exactly the same composition.*
2. *In a mixture, each constituent keeps its own original properties unchanged.*	*The properties of a compound are quite different from those of its constituents.*
3. *The constituents of a mixture lie side by side as separate particles and there is no chemical attraction binding them together.*	*Compounds are the products of chemical changes and their constituents are bound together by chemical attraction.*
4. *The constituents of a mixture can be separated by simple, physical means, without employing chemical reactions.*	*The constituents of a compound cannot be separated by physical means but only by employing chemical changes.*
5. *When a mixture is made there is little or no change in temperature.*	*When a compound is made there is a change in temperature, i.e. heat is given out or taken in during the chemical change.*

EXAMPLES OF MIXTURES:—Air (nitrogen, oxygen, etc.), granite† (quartz,† felspar,† and mica†), brass† (copper and zinc), solder† (tin and lead), garden soil.

EXAMPLES OF COMPOUNDS:—Magnesium oxide, iron sulphide, carbon dioxide, mercuric oxide, copper sulphate, iron oxide.

HOW CAN MIXTURES BE SEPARATED INTO THEIR CONSTITUENTS?

As the separation of mixtures into their constituents is an important operation in many industries, we shall now discuss a few methods of separation by physical means, without employing chemical reactions:

(*a*) A mixture of particles of different sizes can be sorted out by using a *sieve*,* e.g. in separating a mixture of sand and stones.

(*b*) Any magnetic material can be separated from a powdered mixture by using a magnet, as in separating wolfram† (magnetic) from tin-ore† (non-magnetic); or in removing particles of iron from foodstuffs that have been ground up between steel rollers.

(*c*) If one constituent is 'lighter' than the others it can be carried away with a stream of air or water, as in winnowing* grain, and in washing for tin-ore, gold, and diamonds.

(*d*) Sometimes one constituent can be dissolved in a liquid, leaving the other constituents undissolved. Thus salt can be extracted* from a mixture of earth and salt by means of water; gold can be extracted from crushed gold-bearing quartz by dissolving it in mercury or in sodium cyanide† solution.

(*e*) If one constituent melts at a lower temperature than the others, it will flow away when the mixture is heated. For example, sulphur is found mixed with earth and rock; and when the mixture is heated the sulphur melts and flows away.

(*f*) In a mixture of liquids, if one constituent boils at a lower temperature than the others it can be separated by *distillation** (see pp. 110–12). Crude* petroleum,† as it comes from an oil-well, is a mixture of a large number of different substances. When it is boiled, petrol distils* off first, then kerosene, and so on.

How could you separate the following mixtures in the laboratory? (i) Salt and sand. (ii) Petrol and water. (iii) Sand and clay. (iv) Iron and brass filings. (v) Alcohol and water. (vi) Gunpowder† (a mixture of charcoal, sulphur, and nitre†). (vii) Iodine† and powdered glass. (viii) Lead filings and sand.

HOW CAN WE SUMMARIZE CHEMICAL REACTIONS IN WORDS?

We can represent any chemical change or reaction in this way:

IRON + SULPHUR ⟶ IRON SULPHIDE

Each *name* stands for a *substance*. Two substances that are *mixed* but not chemically combined are joined by the + sign. The arrow* → shows where the *chemical change* takes place, and also the direction of the change. In words, this statement reads: *Iron and sulphur, when brought together in a suitable way, combine chemically to form iron sulphide.*

In Book Four, when you understand *chemical formulas** (or *formulae*) we shall shorten these statements still further into *chemical equations.**

WHAT DO THE NAMES OF CHEMICAL COMPOUNDS TELL US?

Notice that there is nothing separating the words '*iron*' and '*sulphide*' in the name *iron sulphide*. This shows that the iron and the sulphur are *chemically combined* or bound together by chemical attraction.

Notice, also, that the chemical name of a substance tells you exactly what elements it contains. If the chemical name ends in *-ide*, then the compound contains only *two* elements, e.g. magnesium oxide, calcium carbide,† hydrogen sulphide,† and sodium chloride.† [1] If the chemical name ends in *-ate*, then the compound contains *oxygen* as well, e.g. copper sulphate, calcium carbonate,† sodium phosphate,† potassium nitrate.†

You will soon realize that *chemical names* tell you much more about substances than *common names*. For example, the chemical name for *common salt* is *sodium chloride*. The name 'common salt' tells you nothing about its chemical composition, but the name 'sodium chloride' shows that it is a compound of the elements 'sodium' and 'chlorine' *and nothing else* (since it ends in *-ide*). Similarly, the chemical name for *washing soda*† is *sodium carbonate*,† showing that it is a compound of sodium, carbon, *and oxygen*. So there is nothing to be afraid of in these chemical names. In fact, the longer they are the more they tell you about the substance.

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[1] The term *hydroxide*† is an exception to this rule (see p. 43).

If a material contains only one element or compound, a chemist* calls it a *pure* substance.

HOW DO SOLIDS MIX WITH LIQUIDS?

When a little common salt is shaken up with plenty of water for a few minutes, we can no longer see the salt; and however long we let it stand, the salt does not settle to the bottom. The salt is said to have *dissolved* in the water, and the uniform* mixture of salt and water is called a *solution* of salt in water.

On the other hand, when a little powdered starch is shaken up with water we get a cloudy mixture. If we look at it closely, with a lens, we can still see bits of starch scattered throughout the water; and when we let it stand for a few minutes, the starch settles to the bottom. The starch has not dissolved, but is only *suspended** in the water. That is, we do not get a solution of starch in water, but only a *suspension.** When we *filter* this suspension (see Fig. 12), all the

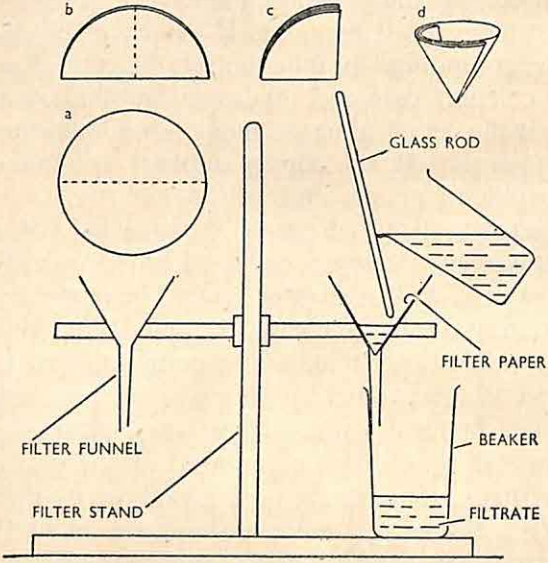

FIG. 12. Filtering.
Figs. a, b, c, and d show how to fold a filter-paper.

starch is left on the filter-paper; but if we filter the solution of salt, nothing remains on the filter-paper, and in order to get back the salt we have to *evaporate** the salt solution to dryness.

Every liquid is a *solvent** for some substance or other, e.g. carbon disulphide dissolves sulphur and rubber, or it is a solvent for these two substances; petrol is a solvent for oil, grease or wax; alcohol is a solvent for shellac† (the mixture forms spirit varnish†); turpentine† dissolves linseed† oil (the mixture is used for making paint and for polishing and preserving laboratory woodwork); mercury will dissolve many other metals; while water is a solvent for thousands of different substances.

HOW TO DO SOME EXPERIMENTS WITH SOLUTIONS

(i) Half fill a test-tube with water and add about 1 gm. of nitre (potassium nitrate). Shake the test-tube vigorously,* closing the mouth of the tube with your thumb.

What happens? ....

What is formed? ....

Place the test-tube in the test-tube stand for a few minutes.

Is there any change on standing? ....

Now add more nitre, about 1 gm. at a time, shaking vigorously after each addition.

What happens at first? ....

What happens after several additions of nitre? ....

....

When no more nitre will dissolve, filter the liquid into a clean, dry test-tube. This *filtrate** (i.e.* the clear liquid that passes through the filter) is a *saturated* solution*† of nitre, because you went on adding nitre until the solution could hold no more. Pour about 5 c.cm. ($1\frac{1}{2}$ in. in a $\frac{5}{8}$-in. test-tube) of your solution on to a clean watch-glass and put it on the water-bath to evaporate. (Keep the remainder of your saturated solution of nitre for a later experiment.) Examine the dry residue on the watch-glass and keep it for comparison with the results of the next two experiments.

(ii) Repeat Experiment (i), using about 1 gm. of slaked lime instead of nitre.

Does *all* the slaked lime dissolve? ....

Does *any* slaked lime dissolve?.........................

To make sure of this, filter the liquid and evaporate about 5 c.cm. of the filtrate to dryness on a watch-glass as in Experiment (i).

Is there any residue, and if so, how much? ....

Is slaked lime more or less *soluble** than nitre?.............

(iii) Again repeat the experiment, using about 1 gm. of finely powdered limestone† or 'chalk' (but *not* 'black-board chalk'). Filter the mixture and evaporate 5 c.cm. to dryness as before.

Is there any residue, and if so, how much?..................

Is limestone more soluble or less soluble than lime? ....

HOW IS SOLUBILITY MEASURED?

Your experiments show that different substances dissolve in water in varying amounts, e.g. nitre is readily soluble in water, lime is slightly soluble in water, while limestone is practically *insoluble*. The amount of a substance that is required to *saturate* a fixed amount of the *solvent* is called its *solubility*.†

The solubility of a substance is the number of grams required to saturate 100 grams of the solvent at a definite temperature. For example, at 30° Centigrade,[1] † 100 gm. of water will dissolve 45 gm. of nitre, i.e. the *solubility* of nitre at 30° C. is 45. In the same way 100 gm. of water at 30° C. will dissolve 36 gm. of common salt, i.e. the solubility of common salt at 30° C. is 36. Again, 100 gm. of water at 30° C. will dissolve 0·15 gm. of slaked lime, i.e. the solubility of slaked lime at 30° C. is 0·15.

By expressing the *relative solubility* of different substances by a *number* we get a much more accurate idea than by using terms like 'very soluble', 'readily soluble', 'slightly soluble', 'almost insoluble', etc.*

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[1] On the Centigrade scale of temperature (which we shall discuss in Book Three) the melting point of ice is taken as 0° C. and the boiling point of water as 100° C.

When a solution contains only a little of the dissolved substance we call it a *dilute*† solution; if it contains a lot of the dissolved substance we call it a *concentrated*† solution. It is better to use these two terms than to speak of 'weak' and 'strong' solutions.

WHAT IS THE EFFECT OF TEMPERATURE ON SOLUBILITY?

Take the saturated solution of nitre that you made in Experiment (i) and warm it slightly. Add about 1 gm. of nitre and shake. What happens?.................................

Is nitre more soluble in hot water than in cold water?........

Warm your solution still more and add another 1 gm. of nitre. What happens? ....

Filter a little of your warm solution into a watch-glass and set it aside to cool. What happens?.........................

What is the effect of rise of temperature on the solubility of nitre?...

After the *solubility* of a substance has been measured at several different temperatures, the relation between solubility and temperature can be shown by a *graph** called *a solubility curve*. Fig. 13 shows the solubility curves of several common compounds. Notice (*a*) that solubility usually increases with rise of temperature, (*b*) the effect of change of temperature on solubility is different for different substances, and (*c*) the change is usually gradual. (The sodium sulphate† curve is an exception and the reason for the sudden change in this curve is explained on p. 44.)

WHAT ARE CRYSTALS?

We have seen that the solubility of nitre is much greater in hot water than in cold water, therefore, if we saturate some hot water with nitre and then allow it to cool, it will become *more than saturated* (or *super-saturated*†) at this lower temperature and some solid nitre will come out of the solution (unless the solution is quite free from dust and is not shaken, when the solution may remain super-saturated).

For example, the solubility of nitre at 30° C. is 45, while its solubility at 80° C. is 170; hence if we shake up an excess of nitre with 100 gm. of water at 80° C. the solution will eventually* take up 170 gm. of nitre, when it will be saturated. If we let the hot

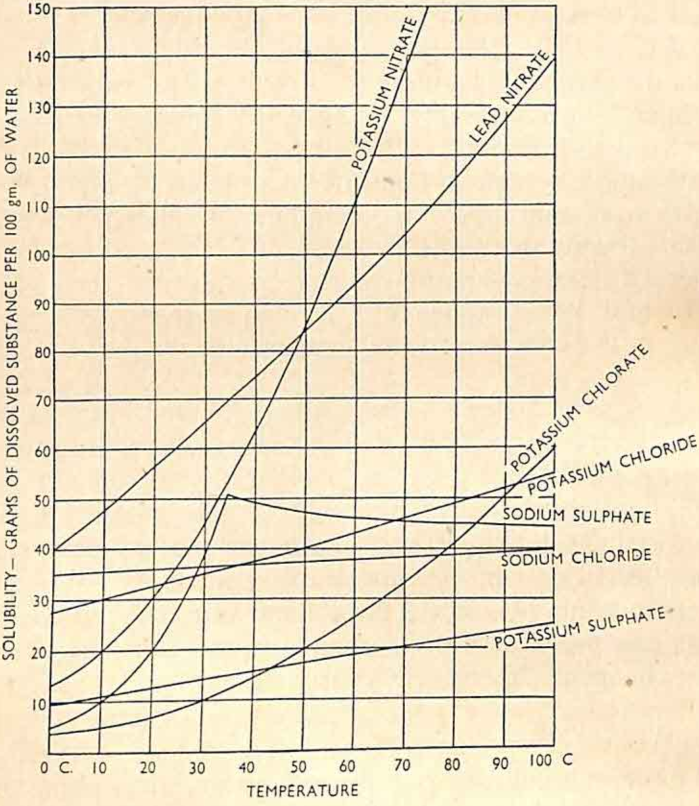


FIG. 13. Solubility curves.

liquid cool down to 30° C. it will become super-saturated, and it will usually deposit* solid nitre (170 − 45 = 125 gm.), and it will then contain only 45 gm. of dissolved nitre.

This excess of nitre does not separate out anyhow, but in particles of characteristic regular geometrical* shape called *crystals*,† and these crystals 'grow' as more and more solid nitre separates from the solution. If the cooling is slow, a few large crystals are formed; but if the cooling is rapid, a lot of very small crystals are formed. When examined with a lens, however, the tiny crystals are seen to have exactly the same geometrical shape as the larger ones.

Your teacher will put drops of various saturated solutions on glass slides under the microscope or micro-projector† so that you can watch the crystals growing as the solution slowly evaporates. Notice that crystals of different substances have different characteristic shapes (see Fig. 14). In fact, many substances can be recognized by the shape of their crystals.

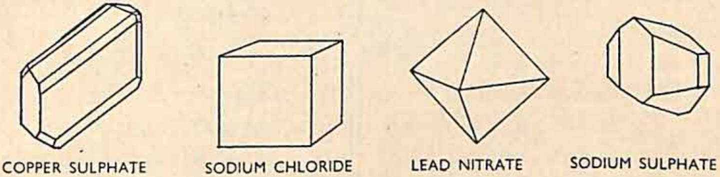


FIG. 14. Some crystals.

Certain substances, as they crystallize, combine with definite amounts of water, called water of crystallization (or *water of hydration*). Such substances, containing water of crystallization, are called *hydrates*.† [1] Although these crystals appear to be quite 'dry', they may contain much water *combined* with the solid in its crystalline state. Thus copper sulphate crystals (copper sulphate hydrate) contain 36 per cent. of water; washing-soda crystals contain 63 per cent. of water of crystallization. It is important to remember that this water is *combined* with the solid, hence the crystals feel quite dry to the touch.

---

[1] This word *hydrate* was formerly applied to substances that we now call hydroxides, so if you sometimes see reagent* bottles labelled* 'Calcium Hydrate', 'Sodium Hydrate', 'Ammonium Hydrate', and 'Potassium Hydrate', remember that the modern names are 'Calcium Hydroxide', 'Sodium Hydroxide',† 'Ammonium Hydroxide',† and 'Potassium Hydroxide'.†

Many substances, however, crystallize from their solutions without combining with any water, e.g. nitre and common salt. Such crystals, which contain *no water of crystallization*, are said to be *anhydrous** (without water).

We can now explain the abnormal* solubility curve for sodium sulphate in Fig. 13, where the curve of increasing solubility (up to 32·4° C.) is for *sodium sulphate hydrate*, and the curve of decreasing solubility is for *anhydrous sodium sulphate*. The hydrate loses its water of crystallization at 32·4° C. and changes into anhydrous sodium sulphate.

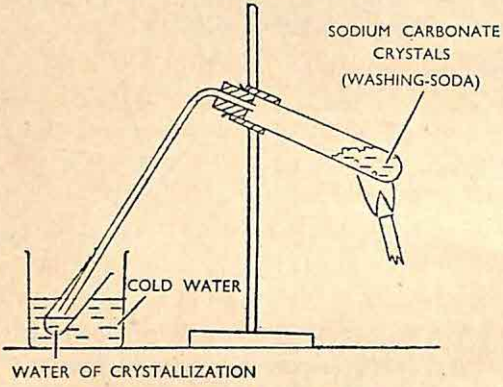


FIG. 15. Water of crystallization.

HOW TO SHOW THAT SOME CRYSTALS CONTAIN WATER OF CRYSTALLIZATION

(i) Half fill a test-tube with washing-soda (sodium carbonate crystals or sodium carbonate hydrate) and fit the tube with a cork carrying a delivery tube, as shown in Fig. 15. Clamp the tube in a sloping position and let the delivery tube dip into a dry test-tube standing in a beaker of cold water. Gently heat the washing soda with a *small* flame. The solid appears to melt, but it is actually dissolving in its own water of crystallization. Continue heating until the soda looks quite dry, allow to cool, and then examine the contents of both test-tubes. The dry residue is 'soda ash' (or *anhydrous sodium carbonate*) while the clear liquid in the other tube is the water that was combined with the soda as *water of crystallization*.

(ii) Repeat Experiment (i), using blue copper sulphate crystals (or copper sulphate hydrate) instead of washing soda, and continue heating *gently* until a nearly white powder is obtained.

After cooling, put a little of this *anhydrous copper sulphate* in a *dry* test-tube and add water, *drop by drop*, from the tap.

What happens? ....

Put some more of your anhydrous copper sulphate in another *dry* test-tube and add a few drops of either kerosene or petrol (which contain no water). What happens?................

....

Anhydrous copper sulphate is white, and the blue colour of copper sulphate crystals is due to their water of crystallization. Hence anhydrous copper sulphate (white) can be used as a *test for water*, and we shall use it for this purpose later.

(iii) Put *one drop* of a strong solution of *cobalt chloride*† on a piece of filter-paper, or blotting-paper, and dry it by holding several inches above a *small* flame, being careful not to burn the paper.

What happens?....................................

Breathe on the spot of *anhydrous cobalt chloride*. What happens?

....

Hence 'cobalt chloride paper' can be used as a delicate test for water, e.g. we can make use of it to show whether our desiccators are working properly by keeping a piece of cobalt chloride paper inside. When the air inside the desiccator is dry, the paper is blue, but as soon as the air becomes damp the paper turns pink, showing that the desiccator needs fresh fused calcium chloride.

Some substances, after their water of crystallization has been driven off by heat, take up water again when exposed to damp air, e.g. the fused calcium chloride in your desiccators was made by heating calcium chloride crystals (or calcium chloride hydrate) until all the water of crystallization was driven off. The fused (or anhydrous) calcium chloride takes up water again whenever it can, actually absorbing* enough water to dissolve itself. Examine some fused calcium chloride that has been exposed to the air of the room for half an hour, on a watch-glass.

CHAPTER III

THE GASES OF THE AIR

OXYGEN

Our earlier experiments showed that the air contains about one-fifth (21 per cent.) of 'active air' or *oxygen*. We have seen that this gas is a most important substance since all life depends on oxygen; without it we should suffocate,* and it is necessary for burning, rusting and ordinary decay.

We have ourselves prepared a little oxygen by heating red mercuric oxide (see p. 26). This was how Priestley discovered oxygen in 1774. About a year later, Lavoisier, a French chemist, carried out some experiments that showed clearly the composition of the air and what actually happens when metals burn or rust in air. In Lavoisier's most famous experiment, he heated some mercury in the apparatus shown in Fig. 16. Mercury rust formed on the surface of the hot mercury, and at the same time the

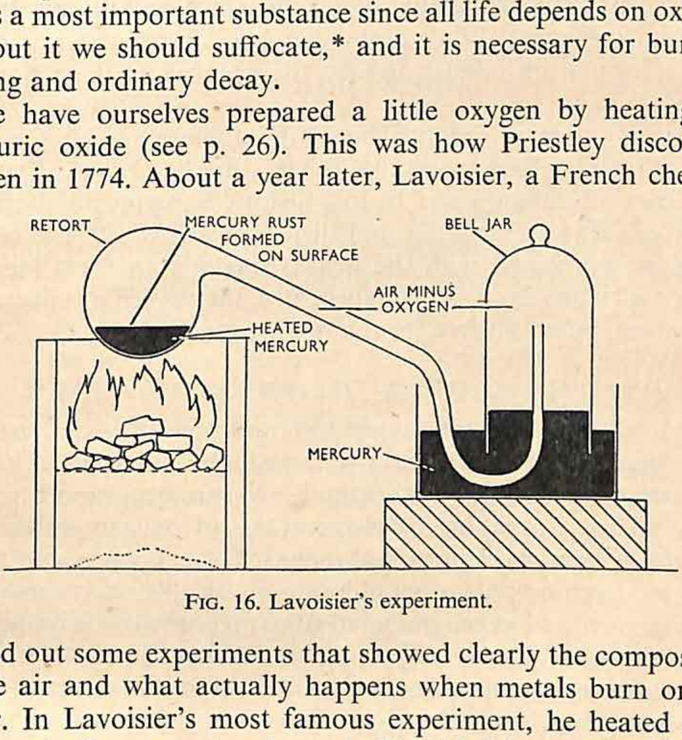


FIG. 16. Lavoisier's experiment.

600° C.). The manganese dioxide only hastens the decomposition of the potassium chlorate, and itself remains unchanged after all the oxygen has been liberated from the potassium chlorate. Such a substance is called a *catalyst*.† We shall learn about other catalysts later.

Catalysts are substances that change the speed of a chemical reaction but themselves remain unchanged at the end of the reaction.

TO PREPARE SEVERAL JARS OF OXYGEN

Thoroughly mix about 9 gm. of potassium chlorate with about 3 gm. of manganese dioxide. Put the mixture in a 'hard' glass test-tube and set up the apparatus shown in Fig. 17.

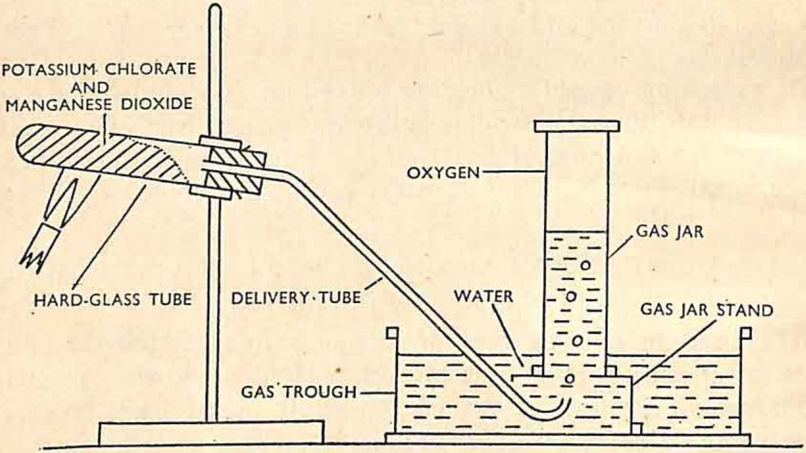


FIG. 17. Preparation of Oxygen.

The test-tube is clamped loosely, sloping as shown in Fig. 17, and is fitted with a cork carrying a delivery-tube. The other end of the delivery-tube dips under a gas-jar stand in a gas-trough which is half-filled with water. When your teacher has approved the apparatus, heat the test-tube *gently*, moving the flame about all the time. If you put the burner under the tube and leave it there, you will probably break the tube. Also be careful that the hot mixture of potassium chlorate and manganese dioxide does not touch the cork. Why?.........................

....

When bubbles of gas begin to come out of the delivery-tube, allow the first few bubbles to escape. Why?.........................

....

Then invert a test-tube, full of water, over the end of the delivery-tube.

Collect four test-tubes and three gas-jars of oxygen, closing the test-tubes with corks and the gas-jars with gas-jar covers when full of oxygen. (N.B.—If the gas is cloudy, you are heating the mixture too strongly.) As soon as you have collected enough oxygen, stop heating and raise the end of the delivery-tube above the surface of the water in the gas-trough. Why?..............

....

1st Tube. (*a*) Has the gas any colour, taste or smell?..........

....

(*b*) Hold a glowing wooden splinter in the gas.

What happens?...............................

Does oxygen burn?...............................

2nd Tube. Invert the tube of oxygen in a beaker containing a little water and leave it until the end of the lesson.

Does oxygen dissolve in water?...........................

Why do you say this?...............................

....

3rd Tube. Pour a little *purple litmus*† *solution* into the tube of oxygen, close with the thumb and shake. What is the action of oxygen on litmus?...............................

4th Tube. Pour a little clear lime-water into the tube of oxygen, close with the thumb and shake. What is the action of oxygen on lime-water?...............................

1st Jar. Lower a small lighted candle into the jar of oxygen.

What happens?...............................

2nd Jar. Put a piece of wood-charcoal (carbon) on a gas-jar spoon and heat one corner of it red-hot in the Bunsen flame. Then hold it in the jar of oxygen (being careful not to let the hot charcoal touch the sides of the jar).

What happens? ....

After the charcoal has finished burning, take out the spoon, add a little lime-water, close the jar with a gas-jar cover, and shake.

What happens?..................................

This is a test for carbon dioxide, which you have *synthesized* by burning the element carbon in the element oxygen.

3rd Jar. Put a little *red phosphorus* in a cool, dry gas-jar spoon, and set fire to it by just touching it with a flame. Put the burning phosphorus into the jar of oxygen.

What happens?..................................

What is formed?................................

FURTHER EXPERIMENTS WITH OXYGEN

Your teacher will prepare several jars of oxygen and show you the following experiments:—

(i) *Burning Sulphur in Oxygen*.—When some sulphur is put in a gas-jar spoon and held in the flame, it melts and catches fire, burning with a faint blue flame which can hardly be seen in daylight. When put into a jar of oxygen, it burns with a much brighter blue flame, forming a cloudy gas which has a characteristic pungent* smell.

This gas is *sulphur dioxide*.† When a little water is put in the jar and shaken up, the sulphur dioxide dissolves in the water, forming sulphur*ous* acid† (*not* sulphur*ic* acid).† As this is the first time that we have made an *acid* we must now learn what this word means.

Acids are substances that have a sour taste and change the colour of litmus (a vegetable dye*) *from blue to red*. (DANGER. Do not taste any chemical unless told to do so by your teacher.)

When some blue litmus solution is put into the jar in which sulphur has been burnt in oxygen, it is turned *red* by the sulphurous acid. Hence, *blue litmus is used in testing for acids*.

(ii) *Burning Carbon in Oxygen.*—When a piece of red-hot wood-charcoal (a form of carbon) is put in a jar of oxygen, it burns quickly, with bright sparks,* and forms a colourless gas, *carbon dioxide*, which, as we have seen in our earlier experiments, turns lime-water 'chalky'. When shaken up with water, some of the carbon dioxide dissolves, and the solution will *just* turn blue litmus solution red, showing that a *weak acid* has been formed. This weak acid, formed when carbon dioxide dissolves in water, is called *carbonic acid*.†

(iii) *Burning Phosphorus in Oxygen.*—Phosphorus burns in oxygen with a bright, yellow flame, forming clouds of *phosphorus pentoxide*.† (As there are several different oxides of phosphorus, they all have to be given different names and this one is called phosphorus pentoxide.) When shaken up with water, the white powder dissolves and the solution turns blue litmus *red*, showing that an acid has been formed. This acid, formed when phosphorus pentoxide dissolves in water, is called *phosphoric acid*.†

Experiments (i) to (iii) show that *when the elements sulphur, carbon, and phosphorus burn in oxygen they form oxides which all dissolve in water to form acids.*

(iv) *Burning Sodium in Oxygen.*—When a piece of sodium is heated in the flame and then put into a jar of oxygen, it burns quickly with a bright yellow flame and forms a cloud of white *sodium oxide*.† This sodium oxide dissolves in water (forming *sodium hydroxide*) and the solution turns red litmus *blue*, showing that an acid is not formed in this case, but something else called an *alkali*.†

Alkalis are substances that have a bitter (*or soapy*) *taste, and which change the colour of litmus from red to blue. Hence litmus is used in testing for both acids and alkalis.*

When an acid and an alkali are mixed in the right proportions, they *neutralize** each other and form a substance that is neither acid nor alkaline, but *neutral*.* For example, when the strong acid hydrochloric acid† is mixed in the right proportions with the strong alkali sodium hydroxide, the product is harmless neutral *sodium chloride* (or *common salt*) which is neither acid nor alkaline and which has no action on litmus.

(v) *Burning Magnesium in Oxygen.*—Magnesium burns in oxygen with a blinding white light and forms white *magnesium oxide*. This dissolves in water slightly, and the solution turns red litmus *blue*, showing that an *alkali* (magnesium hydroxide)† is formed.

(vi) *Burning Calcium in Oxygen.*—When the metal calcium is burnt in oxygen there is a bright red light and *calcium oxide*,† a white solid, is formed. This calcium oxide is slightly soluble in water and the solution turns red litmus *blue*, showing that an *alkali* (calcium hydroxide†) has been formed. When the calcium oxide is shaken up with water it forms a white suspension of calcium hydroxide. On filtering, a clear liquid is obtained which turns 'chalky' when shaken up with expired* air, showing that the liquid is *lime-water*—a saturated solution of calcium hydroxide, synthesized from calcium, oxygen, and water.

(vii) *Burning Iron in Oxygen.*—When a piece of thin iron wire or some steel wool is heated red-hot and quickly put into a jar of oxygen it burns rapidly with bright sparks, forming a blue-black *iron oxide*. (This is not the same oxide of iron as the one in iron rust and as it will attract iron filings it is called magnetic iron oxide.†) This oxide will not dissolve in water, hence it cannot form an acid or an alkali and can have no action on litmus.

WHAT DO WE LEARN FROM OUR EXPERIMENTS ON BURNING ELEMENTS IN OXYGEN?

Our experiments show that these seven elements can be classified in two groups according to whether they produce acid-forming or alkali-forming oxides.

(*a*) *When non-metals* (e.g. carbon, sulphur, phosphorus) *burn in oxygen they form acidic oxides which combine with water to form acids.*

(*b*) *When metals* (e.g. sodium, calcium, magnesium, iron) *burn in oxygen they form basic oxides*† *and those basic oxides that dissolve in water form alkalis.*

In Book Two we shall deal in more detail with these three important classes of compounds—*acids, bases,† and alkalis*.

WHAT ARE THE PROPERTIES OF OXYGEN?

Oxygen is a gas without colour, taste, or smell. It is slightly 'heavier' than air. (Oxygen is sixteen times 'heavier' than hydrogen, the lightest of all gases, while air is a little over fourteen times 'heavier' than hydrogen.) Oxygen is only slightly soluble in water,[1] although enough of it dissolves to supply water-plants and animals with the oxygen that they require. (100 c.cm. of water at 0° C. dissolves about 5 c.cm. of oxygen—as the temperature of the water rises the solubility of oxygen becomes less.)

The most important chemical property of oxygen is its power of supporting combustion: any substance that will burn in air burns much more rapidly in oxygen. Oxygen is essential for breathing, burning, rusting and ordinary decay, and all such chemical changes, where substances combine with oxygen, are called *oxidations*.†

Oxygen is the most plentiful element in the Earth's crust (including the seas and the atmosphere).

WHAT ARE THE EVERYDAY USES OF OXYGEN?

Since the atmosphere contains about 21 per cent. of oxygen, this is the cheapest source of the gas, and most of the oxygen that is used for industrial purposes is now obtained from the air. The air is first liquefied by great cooling (to about − 200° C.), giving a mixture of *liquid oxygen and liquid nitrogen*. If this *liquid air* is allowed to evaporate, the nitrogen boils off first (at − 196° C.) leaving liquid oxygen behind. The liquid oxygen is then allowed to boil (at − 188° C.) and the oxygen gas, as it comes off, is compressed by pumps into strong steel cylinders.

---

[1] Solubility of gases: When describing the solubility of gases we shall use the term '*slightly soluble*' to mean that 1 volume of cold water (at 0° C.) dissolves less than 1 volume of the gas at ordinary pressure. By '*moderately soluble*' we mean that not more than 10 volumes of the gas will dissolve in 1 volume of water. By '*very soluble*' we mean that more than 10 volumes of the gas will dissolve in 1 volume of water.

Oxygen is used by doctors when the patient's lungs* are not working properly, e.g. in cases of suffocation by drowning or by poisonous gases. It is also used under conditions where ordinary breathing is difficult or dangerous, e.g. by airmen flying at great heights and by mine rescue workers.

Oxygen is used in large quantities for producing very hot flames for cutting and welding* metals, e.g. the *oxy-hydrogen flame* (hydrogen burning in oxygen) gives a temperature of over 2,000° C., while the *oxy-acetylene flame* (acetylene† burning in oxygen) gives a temperature of over 3,000° C. This is hot enough to 'cut' through a steel plate one foot thick.

NITROGEN

Our early experiments showed that about four-fifths of the air (78 per cent.) is 'inactive air'—mainly *nitrogen.* Nitrogen can be obtained from the air by removing the oxygen, but the gas obtained in this way is not quite pure since it still contains the 'rare gases' and a little carbon dioxide.

We have learnt that Lavoisier, in 1775, was the first man to prove that air is made up of two different gases, oxygen and nitrogen, and that the oxygen alone combines with metals during rusting and burning (see p. 47). We shall not use Lavoisier's method for preparing nitrogen, using mercury to remove the oxygen, because the action is so slow (Lavoisier's experiment took about twelve days). By using *phosphorus* to remove the oxygen we can carry out a similar experiment in about twelve minutes.

HOW TO OBTAIN SOME NITROGEN (AIR MINUS* OXYGEN)

Fix a crucible-lid on a flat cork floating in a gas-trough containing a shallow layer* of water, and put a *small* piece of *yellow phosphorus* (DANGER!) on the lid. Set fire to the phosphorus by touching it with a hot wire, and quickly invert a gas-jar over the burning phosphorus (see Fig. 18). The phosphorus, in burning, combines with the oxygen of the air, forming phosphorus pentoxide, which we see as a cloud of white powder filling the jar. After

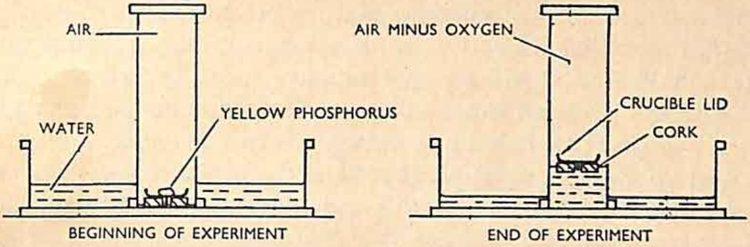


FIG. 18. Obtaining Nitrogen from air.

a time, the phosphorus pentoxide dissolves in the water, leaving 'inactive air', which is mainly nitrogen, in the jar. Each pair of pupils now has one jar about four-fifths full of nitrogen, and as there are several experiments to do they must be done by different pupils (unless your teacher provides more jars and test-tubes of nitrogen prepared by a more complicated method).

(i) Describe the colour, taste and smell of nitrogen...........
....

(ii) Find out whether the gas is soluble in water..............
....

(iii) Does nitrogen support combustion? Test this with (*a*) a lighted candle and (*b*) burning sulphur......................
....

(iv) Test your nitrogen with lime-water.

What happens?..................................

How could you distinguish between nitrogen and carbon dioxide? ....
....

WHAT ARE THE PROPERTIES OF NITROGEN?

Nitrogen is a gas with neither colour, nor taste, nor smell. It is slightly 'lighter' than air.

(Nitrogen is fourteen times 'heavier' than hydrogen, the lightest of all gases, while air is a little over fourteen times 'heavier'.) It is only slightly soluble in water (and less soluble than oxygen).

Nitrogen does not itself burn and it does not support combustion. Nitrogen has no action on litmus and it does not turn lime-water 'chalky'. You will see that we have spoken of all the things that nitrogen will *not* do. In fact, we have not noticed anything that it *will* do. This is because *nitrogen is so very inactive that it is not easy to make it combine directly with other elements*. Oxygen, on the other hand, is *very active* and combines readily with most other elements.

We have now prepared and examined the properties of the two chief constituents of the air, oxygen and nitrogen. These two gases together make up nearly 99 per cent. of the air. The remaining 1 per cent. is mainly *argon*, and there is also a very small quantity of *carbon dioxide* (0·03 per cent), but although there is so very little of the latter, yet it is extremely important in everyday life, as we shall learn later.

CARBON DIOXIDE

Carbon dioxide is formed when we burn charcoal (carbon) in air or in oxygen. Written briefly,

CARBON + OXYGEN ⟶ CARBON DIOXIDE

Carbon dioxide is always formed when any substance containing the element *carbon* is burnt in air or oxygen. All our common *fuels* (substances burnt to provide *heat*), e.g. wood, charcoal, coal, and oil, are chemical compounds containing carbon, and when they burn in air they form carbon dioxide. Carbon dioxide is also formed during *breathing* and during ordinary *decay*.

HOW TO SHOW THAT CARBON DIOXIDE IS FORMED WHEN FUELS BURN IN AIR

Hold a clean, *dry* gas-jar for a few seconds over each of the following (but do not let the flame touch the glass or you may break the jar): (*a*) a burning wooden splinter, (*b*) a lighted candle, (*c*) the flame of an oil lamp (burning kerosene), (*d*) the flame of a spirit lamp (burning alcohol), (*e*) a *small* Bunsen flame (burning ....).

Is there any change in the appearance of the jar in each case?

(*a*) .... (*b*) ....

(*c*) .... (*d*) ....

(*e*) ....

After each experiment, add a little clear lime-water, close the mouth of the jar with a gas-jar cover, and shake.

What happens in each case? ....

....

What does this result show? ....

....

AIR AND LIVING THINGS

In Chapter II we learnt about the different kinds of matter, and about its classification into solids, liquids, and gases, and also into elements, mixtures, and compounds. Living things, however, are very complicated and highly 'organized' arrangements of matter,[1] and they have many properties that are not possessed by the individual* substances from which they are built up. Biologists* describe these properties and try to explain them in just the same way as chemists and physicists* try to explain the properties of elements and compounds.

There are very many different kinds of living things. Those that are simplest in structure* can only be seen under a powerful microscope,† the largest are plants several hundred feet long (e.g. some forest trees and some brown seaweeds†) and animals that weigh many thousands of pounds (e.g. whales† and elephants†). But one property is common to nearly all these living things; *they must all have air* (or water containing dissolved air) and they bring about changes in the composition of the air they use.

---

[1] Living things are often called '*organisms*'.*

(i) Collect some expired air (i.e. 'breathed-out air') as follows:— Fill a gas-jar with water, cover the mouth of the jar with a gas-jar cover, and invert it in a trough of water. Put one end of a glass or rubber tube under the mouth of the jar and blow through the other end until the jar is full of air from your lungs (see Fig. 19). Then remove the tube, close the jar with its cover and lift it out of the trough. Invert this jar of expired air over a lighted candle, count the number of seconds until the flame goes out, and enter the figure below. Light the candle again after removing the jar, and then invert a similar jar of *fresh air* over the lighted candle, again noting the time taken for the flame to go out.

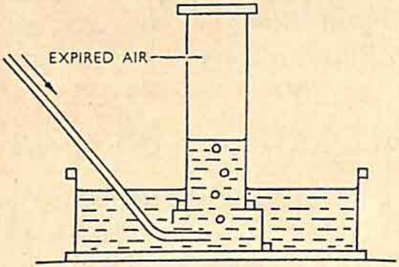


FIG. 19. Collecting expired air.

The candle burnt for ...... seconds in expired air and for ...... seconds in fresh air.

The candle burns for a shorter time in expired air because there is less oxygen present than in fresh air. The flame does not go out at once, however, showing that breathing does not use up *all* the oxygen.

(ii) (*a*) Collect another jar of expired air. Pour some clear lime-water into the jar, close with a gas-jar cover, and shake.

What happens? ....

(*b*) Pour some clear lime-water into a jar of fresh air, close with a gas-jar cover, and shake.

What happens? ....

What do you learn from experiments (*a*) and (*b*)?............

....

(iii) Using the apparatus shown in Fig. 20, first draw fresh air through some clear lime-water in tube 'A', and then, after it has been inside your lungs, breathe it out again through the lime-water in tube 'B'. Pinch your nose while you breathe in and out in this way for some time.

What happens?..............................

What does this show?........................

....

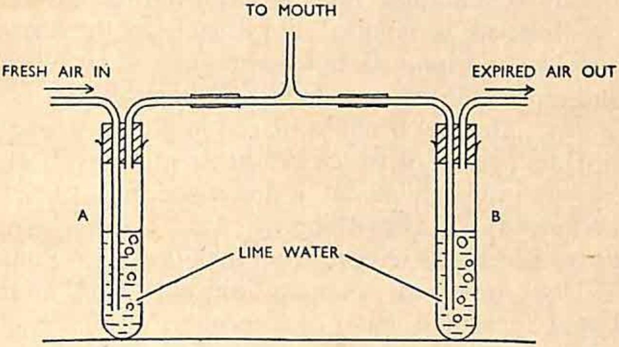


FIG. 20. Changes produced in air by breathing.

These experiments show that when a man breathes he uses up some of the oxygen in the air that he breathes in, and he expires a mixture of gases containing less oxygen and more carbon dioxide. More accurate experiments show that the air we breathe *in* contains about 21 per cent. of oxygen, 78 per cent. of nitrogen, and 0·03 per cent. of carbon dioxide, while the gas we breathe *out* (expired air) contains about 16 per cent. of oxygen, 78 per cent. of nitrogen, and 4 per cent. of carbon dioxide (i.e. it usually contains over 100 times as much carbon dioxide as does fresh air).

Experiments have shown that other animals (e.g. cats, dogs, birds, and frogs†) breathe similarly. We know that as soon as an animal is dead, its breathing stops and that, if an animal is prevented from breathing, it dies from suffocation.

Plants, and many 'lower' animals such as *insects*, *worms*, and *snails*,† are built differently from *mammals*† such as Man, and they do not breathe air through a mouth or nose into *lungs*. But they bring about the same changes in the composition of the air as do mammals when breathing.

WHY DO LIVING THINGS NEED AIR?

We all know that animals must have air in order to live. When a person is drowned, he is killed, not directly by the water (which is not in the least poisonous), but because the water fills his nose, mouth, and lungs and prevents him from breathing. It is possible to 'drown' (or suffocate) if one is placed in pure nitrogen or pure carbon dioxide, neither of which is a poisonous gas. If an animal is enclosed in an air-tight vessel, it dies when most of the oxygen has been removed by its breathing.

Living organisms take oxygen from the air and give out carbon dioxide. These important changes are part (the more easily observed and measured part) of a process* called *respiration*† which takes place in all living organisms. It is a form of *oxidation*, closely similar to the rusting of iron and the burning of fuels. When iron rusts, oxygen is taken up and iron oxide is formed; this oxide sticks to the surface of the iron, which therefore increases in weight. When a candle burns, oxygen is used up and carbon dioxide is formed. This oxide is, however, a gas, and it escapes into the air; so the candle loses weight. Like the candle, living things contain carbon compounds, and during respiration some of these compounds are oxidized; the carbon dioxide escapes into the air, so the organism loses weight.

Respiration, therefore, is rather like the burning of a carbon compound, in that carbon dioxide is set free; but it is, from another point of view, more like rusting, for it takes place readily at quite *low* temperatures.

DO LIVING THINGS CHANGE IN WEIGHT DURING RESPIRATION?

It is not easy to measure directly the small change of weight in a plant or animal due to respiration, for greater changes in weight due to other processes (e.g. intake and loss of water) are going on at the same time. The sort of experiment required is as follows:

Take 100 wheat or rice grains and heat them in an oven, for 24 hours, at 100° C.; cool in a desiccator and weigh. The weight (W. gm.) gives the *dry weight* of an average sample of 100 seeds. Now take another sample of 100 similar seeds which have not been heated. Soak these seeds in water for a day and put them to germinate* *in the dark* on wet filter paper in a flat dish with a loose-fitting cover. At the end of a week, drive off the water that the seeds and seedlings* have taken up, by heating all the plants to 100° C. in the oven (first removing all pieces of filter paper). Then cool in a desiccator and weigh. The second weight gives the dry weight of 100 germinated seeds that have been respiring for a week.

Dry weight of 100 seeds (W) = ... gm.
Dry weight of 100 seedlings = ... gm.
Difference (gain or loss?)................ gm.

Therefore, loss of weight due to respiration by 100 seeds in .... days = ... gm.

THE RELATION BETWEEN RESPIRATION AND ENERGY

When a candle or a piece of wood is burnt, some of the energy in the chemical compounds is changed into other forms of energy, e.g. *light energy* and *heat energy*. During the rusting of iron the same sort of energy changes take place, but the reaction is going on so slowly that we do not notice them. Whenever *respiration* is going on, changes also take place in the *form* of the energy that is locked up in the plant or animal. *The real value of respiration, to plants and animals, is that it liberates a supply of energy in a new form.* A steam engine cannot work unless we supply it with *fuel*, burning this fuel to heat the water in the boiler. Neither can a plant or animal work (i.e. move, grow, and develop) unless its own special sort of fuel (a carbon compound) is *respired* and the energy stored in the fuel changed into a useful form.

HOW TO SHOW THAT CARBON DIOXIDE IS FORMED DURING DECAY

Set up the apparatus shown in Fig. 21. Put clear lime-water in the test-tubes 'B' and 'C' and some decaying leaves in the flask 'A'.

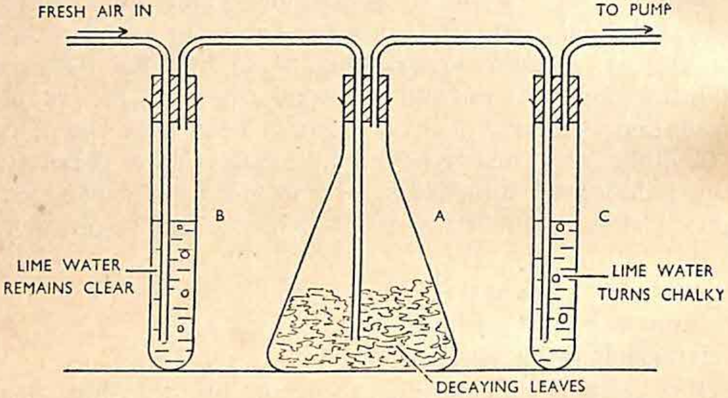


FIG. 21. Carbon dioxide formed during decay.

What happens when air is drawn through the apparatus?:—

(i) To the lime-water in 'B'?........................

(ii) To the lime-water in 'C'?........................

What does this result show? ....

....

What is the object of using the tube 'B'? ....

....

Although it is not possible at this stage to show that the decaying material itself does not cause the changes you observe, it can be proved that these changes in the air are due to the presence of millions of microscopic creatures (e.g. bacteria and moulds) in the decaying material.

THE CIRCULATION* OF CARBON DIOXIDE IN NATURE

Carbon dioxide is formed in everyday life by (a) the burning of fuels, (b) the breathing of living things, and (c) the decay of plant and animal remains.

Burning, breathing, and decay have been going on in the world for thousands of years, and the total amount of carbon dioxide formed during all those years must have been very great indeed. Yet there is only about 0·03 per cent. of carbon dioxide in the air and this proportion hardly changes at all. This is because *green plants use a lot of carbon dioxide from the air*. They use the *carbon* to build up their roots, stems, branches, leaves, flowers, and fruits; and they return *oxygen* to the air in place of the carbon dioxide that they take in. We shall now show that this is so for a green water-plant, and in later lessons we shall show that the same is true of a land plant.

HOW TO SHOW THAT GREEN PLANTS TAKE IN CARBON DIOXIDE AND LIBERATE OXYGEN IN SUNLIGHT

Fit up two large flasks as shown in Fig. 22. Fill flask 'A' with water through which carbon dioxide has been bubbled for some time, i.e. a dilute solution of carbon dioxide. Fill flask 'B' with water that has been boiled to drive out any carbon dioxide and then cooled in a covered vessel. Put some *green water-weed* in both flasks and put them *in bright sunlight* out of doors. Invert a test-tube, filled completely with boiled and cooled water, in each funnel.

Notice that bubbles of gas are formed on the leaves of the plant in flask 'A' (but not in 'B'). In time these bubbles rise and collect in the test-tube. When there is enough gas to test, remove the test-tube, closing the mouth of the tube with the thumb, and put a glowing wooden splinter in the gas. It bursts into flame, showing that the gas is mainly *oxygen*. In the other flask 'B', where the water contains no carbon dioxide, no oxygen is given off. If a similar *control experiment* is carried out, in which both flasks are kept *in the dark*, *no gas is set free*.

These experiments show that *green plants, when exposed to sunlight and supplied with carbon dioxide, give off oxygen.*

It can be shown, by using more complicated apparatus, that they also *take in carbon dioxide* under such conditions, but our simple experiments have not yet proved this additional fact. This intake of carbon dioxide is the reason why the amount of carbon dioxide in the air is always very nearly the same, 0·03 per cent: the green plants that cover so much of the Earth's surface use up the millions of tons of carbon dioxide formed each day by burning, breathing, and decay as fast as it is formed, and give out oxygen in its place. Hence the air keeps 'fresh' and fit to breathe. If there were no green plants, the oxygen of the air would be steadily used up during burning, breathing, and decay, and carbon dioxide would take its place, so that, in time, the air would no longer be fit to breathe.

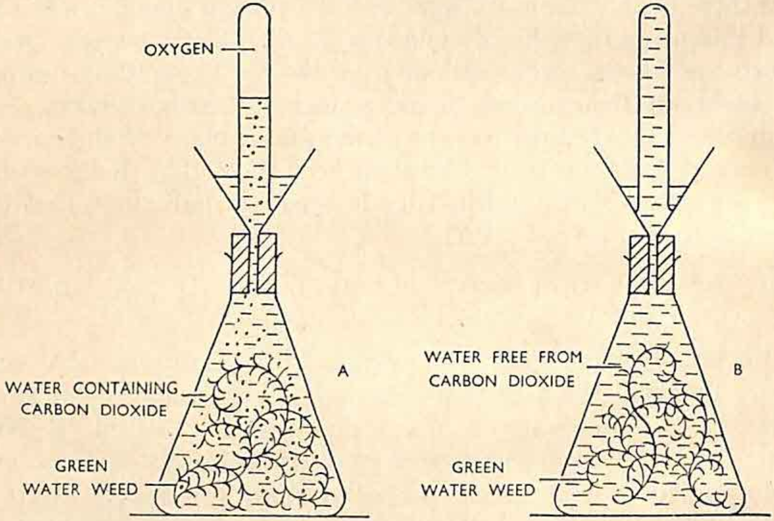

OXYGEN
A
WATER CONTAINING CARBON DIOXIDE
GREEN WATER WEED
WATER FREE FROM CARBON DIOXIDE
B
GREEN WATER WEED

FIG. 22. Oxygen set free by green leaves in sunlight.

These facts concern all of us in our everyday life, and this use of carbon dioxide by green plants in sunlight is one of the most important processes in Nature. Indirectly, through plants, carbon dioxide provides most of our food. Rice, wheat, and sugar are all plant products. We can only get meat, milk, and eggs to eat so long as other animals have green plants to feed on. Even our clothes come from plants (e.g. cotton, rubber) or from animals that feed on plants (e.g. wool, silk, leather). The wood we use as a fuel and for so many other things was made partly from the carbon dioxide of the air. The coal that drives steam engines is only the remains of green plants that lived millions of years ago. The diagram of 'The Carbon Cycle'* in Fig. 23 summarizes all these changes.

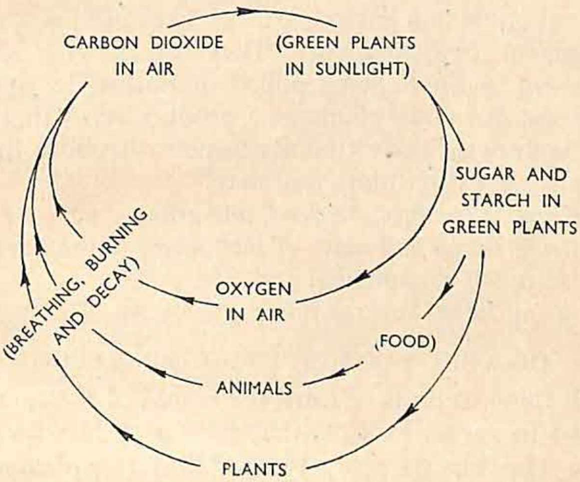

CARBON DIOXIDE IN AIR
(GREEN PLANTS IN SUNLIGHT)
SUGAR AND STARCH IN GREEN PLANTS
(BREATHING, BURNING AND DECAY)
OXYGEN IN AIR
(FOOD)
ANIMALS
PLANTS

FIG. 23. The Carbon Cycle.

We see, therefore, that *all life depends upon green plants being able to use the carbon dioxide of the air in sunlight. We breathe out carbon dioxide as a waste product, but the green plants change it back again into useful things*. We shall learn a lot more about this wonderful process later.

Learning Exercises on Chapters I, II and III will be found on pp. 1–5 of *General Science Workbook I*.

CHAPTER IV

PLANT LIFE

We are now beginning the study of plants, and the first thing to be quite clear about is that *plants are alive*. They need *air*, *water*, and *food* to *breathe*, *feed*, and *grow*. They can *move of themselves*, during growth, without being pulled or pushed by any outside force, and the flowering plants also produce *seeds* that grow up into new plants of the same kind. Remember, therefore, that plants, like animals, are living things and that

(i) *all living things breathe, feed, and grow,*

(ii) *all living things can move of themselves* (although plants do not move so much as animals), and

(iii) *all living things can reproduce themselves.*

WHAT ARE THE CHIEF PARTS OF A FLOWERING PLANT?

The first thing to do is to learn the names of the chief parts of a plant and to get an idea of what each part does for the plant as a whole. The chief parts of a typical* flowering plant are (*a*) the *root*, (*b*) the *stem*, (*c*) the *leaves*, (*d*) the *flowers*, (*e*) the *fruits* and (*f*) the *seeds*. The first three—root, stem, and leaves—are always present, but the last three—flowers, fruits, and seeds—are produced only occasionally during the life of the plant.

We shall now examine a Balsam† plant (see Fig. 24) as an example of a typical flowering plant, because it grows readily and can be found in almost every garden. In the tropics, there is seldom any difficulty in finding a Balsam plant bearing flowers, fruits, and seeds, all at the same time.

THE ROOT

The root grows in the soil and it has two main uses:—(i) *The root takes in, from the soil, water and substances that are dissolved*

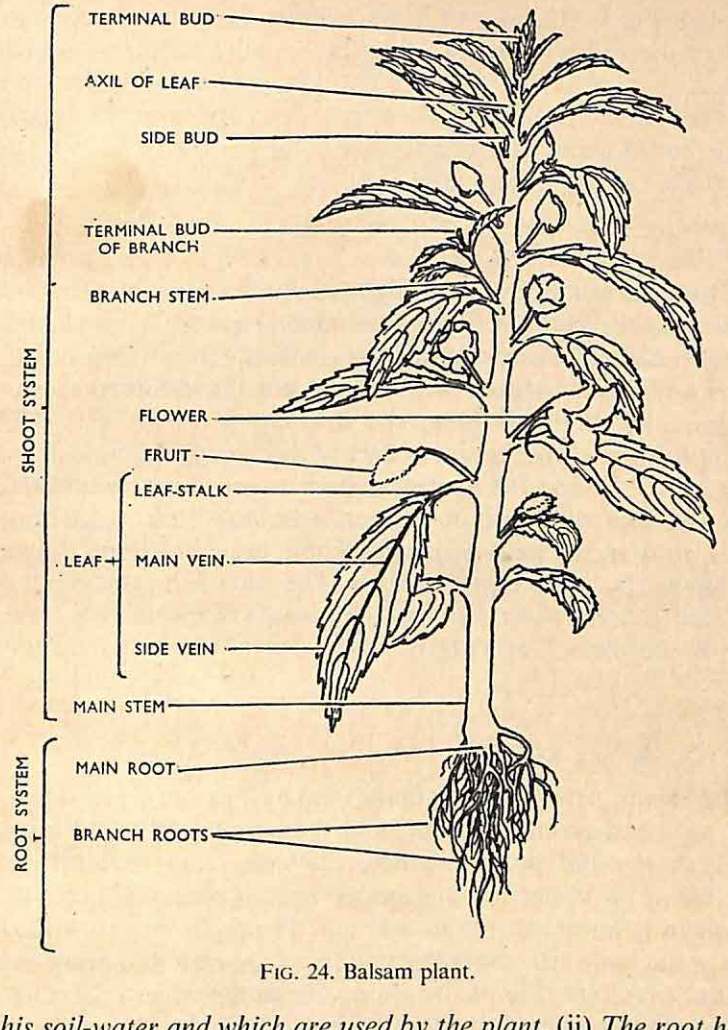


FIG. 24. Balsam plant.

in this soil-water and which are used by the plant. (ii) *The root holds the plant firmly in the soil.*

When we dig up a Balsam plant *very carefully*, we find that the roots have grown through the soil in all directions, thus holding the plant firmly. If the root is washed gently under a tap, so as to remove the soil without breaking the smaller roots, we find that the *main root* usually grows straight downwards, while the *branch-roots* (which are rather like the main root in appearance) slope outwards and downwards. The root is usually white or yellow and *it never bears leaves of any kind.*

THE STEM

The stem usually grows straight upwards above the ground and *it holds out the leaves in the best position for getting as much light as possible*. The stem carries raw food-materials from the roots to the leaves and manufactured food-stuffs from the leaves to the roots. At times, the stem also bears the flowers.

The *main stem* bears leaves and *branch-stems.* Each leaf grows on a *leaf-stalk*, and the acute* angle between the stem and a leaf-stalk is called the *axil*† of the leaf. *Axillary buds*† and branch-stems grow in the axils of leaves. These branches slope outwards and upwards, bearing green leaves. The top of the stem ends in a bud, called the *terminal bud,*† which consists of the delicate growing end of the stem, covered over with tiny, folded, partly grown leaves.

THE LEAVES

The leaves grow from the main stem and its branches. They are thin, flat, and green in colour, and they are usually held out in a nearly horizontal position where they receive as much light as possible. The upper surface of the leaf is smooth and slightly darker in colour than the under side. The *main vein*† is an extension of the leaf-stalk along the middle of the leaf, and *branch-veins* run out on either side of the main vein to the edges of the leaf.

These branch-veins divide up into still smaller veins that join together to form a network which forms the '*skeleton*'† of the leaf. The green leaves are a very important part of the plant since *they build up the plant's food from the carbon dioxide of the air and water* *(containing dissolved substances) supplied by the roots, with the help of sunlight.*

THE FLOWERS

A plant like a Balsam always has a root, stem, and leaves, but during the later part of its life it usually bears flowers and fruits as well. The flowers grow from the main stem, in the axils of leaves, and their only use to the plant is *to produce fruits and seeds.* The Balsam, like many other plants, needs the help of *insects* to do this, and the flowers are attractive to bees, being *coloured* and *sweet-smelling*, and *containing a sugary liquid called nectar*† (which bees make into honey†). The young flower is enclosed and protected in a *flower-bud* until it opens.

THE FRUITS

After the flowers have been open for some time, the coloured part dries up and falls off, but the green parts of the flower usually remain on the plant and grow bigger, forming the *fruit*,† which contains a large number of small *seeds.* The fruit first *protects the seeds*, and then *scatters them.* The Balsam has an 'explosive' fruit and, when the seeds are ripe, a slight touch makes the dry fruit fly open or explode, throwing the seeds some distance away from the parent plant. (N.B.—The scientific term 'fruit' means 'that part of the plant which contains the seeds', whether we can eat it or not.)

THE SEEDS

A ripe seed is really *a very young plant*, with the beginnings of a root, a stem, and leaves, so that it can grow up into a new plant. In this way, plants *reproduce* themselves.

It is often convenient to classify all these plant parts into two main *systems* of parts:—(*a*) the *root-system*† (consisting of the main root and the branch roots), and (*b*) the *shoot-system*† (consisting of all the parts that grow above the ground—main stem, branch stems, leaves, and flowers).

THE BEAN SEED

A dry bean† seed feels quite hard and is covered with a skin or *seed-coat*. On one side of the seed can be seen a scar* which shows where the seed was once attached to the fruit (the bean-pod†) (see Fig. 25). If the bean is soaked in water for some hours, it becomes larger in size and softer. This increase in size, due to intake of water, is not true *growth*, however, for if it dried again the bean returns to its original shape, size, and appearance. Water enters the seed partly through the seed-coat and partly through a tiny hole near one end of the scar (see Fig. 25). If the soaked seed is pressed between finger and thumb, a little water comes out of this opening. The seed-coat can be easily removed from the soaked seed and it is found to be quite thick and tough. Inside the seed-coat we find the *seed-plant* (or *embryo*†), made up of the tiny *seed-root* and the *seed-shoot*. Joined to this seed-plant (and forming the greater part of the bean-seed) are two large, fleshy *seed-leaves* (or *cotyledons*†), full of food material on which the young plant feeds

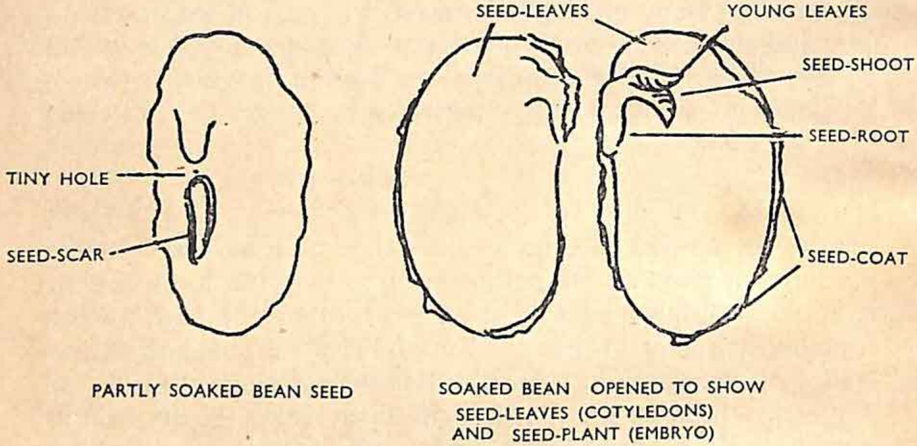
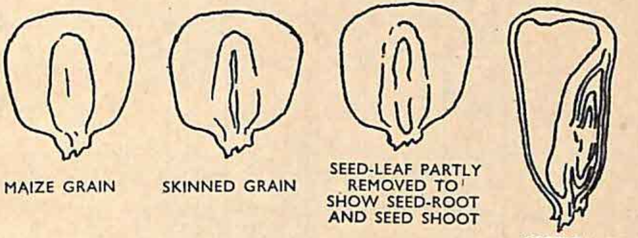


FIG. 25. A bean seed.

until it is able to make its own food. The seed-leaves are joined together by the young *seed-plant*, and the tip of the *seed-root* sticks out from between the seed-leaves. If the seed-leaves are pulled apart, the *seed-shoot* is found between them. This is a tiny bud with some small yellow *leaves* folded round the growing end of the seed-stem. These tiny yellow leaves later become the first green leaves of the young plant.

THE MAIZE GRAIN

The maize grain is a seed that is still enclosed in a fruit, the wall of which is attached to the seed-coat. It shows a scar where the grain was attached to the maize-cob.† The seed-plant (or *embryo*) occupies only part of the seed and its position is shown by the paler, shield-shaped patch on one flat face of the grain. The rest of the grain consists of food which is stored *outside* the seed-plant (and not inside the seed-leaf as in the bean). If a soaked maize grain is cut through with a sharp knife down the middle of one of its flat faces, the seed-plant can be seen in section (see Fig. 26). If we take another soaked maize grain, we can dissect* out the tiny seed-plant. First cut through the outer coat, down the middle of the shield-shaped patch, and through the outer part of the seed-leaf. Turn back the cut edges and then take out the seed-plant, or embryo, with the help of two needles (or pins). This needs great care, as the seed-plant is very small and is easily damaged. Examine


MAIZE GRAIN

SKINNED GRAIN

SEED-LEAF PARTLY REMOVED TO SHOW SEED-ROOT AND SEED SHOOT

SECTION OF MAIZE GRAIN

Fig. 26. A maize grain.

it with a lens and recognize the *seed-root*, the *seed-shoot*, and the single *seed-leaf* (or *cotyledon*) which, however, is not much like a leaf. It consists of a flat, shield-shaped part (which later absorbs food from the rest of the seed) and two close-fitting tubes, one covering the seed-root and the other covering the seed-stem.

WHAT CONDITIONS ARE NECESSARY FOR GERMINATION?

If seeds are kept dry, they show no signs of life. Before such a seed can begin to grow, or *germinate*, (*a*) *water must be present*, (*b*) *oxygen* (in air) *must be present*, and (*c*) *the temperature must be neither too high nor too low* (usually between 10° C. and 30° C.).

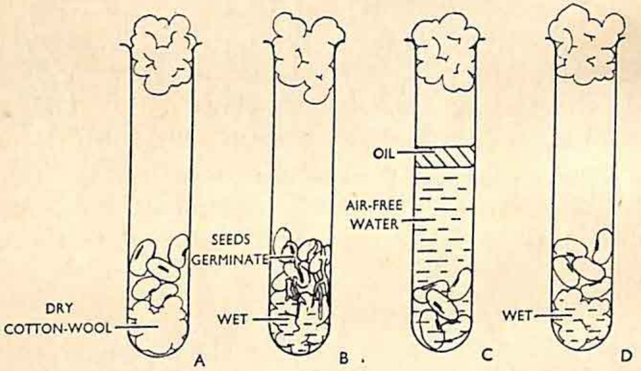


FIG. 27. Experiment showing conditions necessary for germination.

A. With air and warmth (but without water).
B. With air and water and warmth.
C. With water and warmth (but without air).
D. With air and water (but without warmth—in ice-box).

There is no difficulty about (*c*) in tropical countries, where the temperature is nearly always suitable for germination. We can show that these three conditions are necessary by the following simple experiments (see Fig. 27).

To show that water is necessary for germination.—Put a few dry seeds (e.g. Cow-peas†) on cotton-wool in two test-tubes 'A' and 'B', the cotton-wool being *dry* in 'A' and *wet* in 'B'. Keep both tubes in a warm room so that the seeds in 'A' have air and warmth, but *no water*, while those in 'B' have air, warmth *and water*.

What happens after a few days in a warm room?...........

....

What does the experiment show?.........................

....

To show that air is necessary for germination.—Put a few similar seeds in a test-tube 'C' containing *air-free water* (prepared by boiling some water to drive out the dissolved air, and then cooling it under a layer of oil to stop air entering again). Keep this tube 'C' with tubes 'A' and 'B' in a warm room, so that the seeds in 'C' have water and warmth, but *no air*, while those in 'B' have water, warmth, *and air*. Compare 'B' and 'C' after a few days.

What do you see?..................................

What does this show?.............................

To show that suitable warmth is necessary for germination.—Put a few similar seeds on wet cotton-wool in a test-tube 'D', and keep the tube in an ice-box (or a moderately-cold refrigerator*) for a week, so that the seeds in 'D' have water and air, *but little warmth*, while those in 'B' have water, air, *and more warmth*. Compare 'B' and 'D' after a week.

What do you see?..................................

What does this show?.............................

HOW BEAN SEEDS GERMINATE

When a seed germinates in the soil we cannot see what happens unless we dig up the seeds from time to time. But if we use glass vessels, lined with blotting-paper and filled with damp sawdust* or wet moss,† putting the seeds between the glass and the blotting-paper, we can see all the changes that take place without interfering with the growth of the plant (see Fig. 28).

When we plant soaked bean seeds in this way, we see that the seed-coat first splits near the tiny hole opposite the end of the seed-scar. Then the seed-root comes out and soon grows *downwards*, whatever the original position of the seed. The seed-shoot grows more slowly and pushes itself out, curved like a hook (thus protecting the delicate bud at the end of the seed-stem).

From the time that a young plant begins to germinate until it can make its own food it is called a *seedling*. As the seedling grows, it uses up the food stored in its seed-leaves. Notice what happens after cutting off the seed-leaves at various stages in germination, and explain your results.

Some kinds of beans push their seed-leaves up above the ground together with the seed-shoot, and both the seed-leaves and the tiny folded leaves turn green when they reach the light.

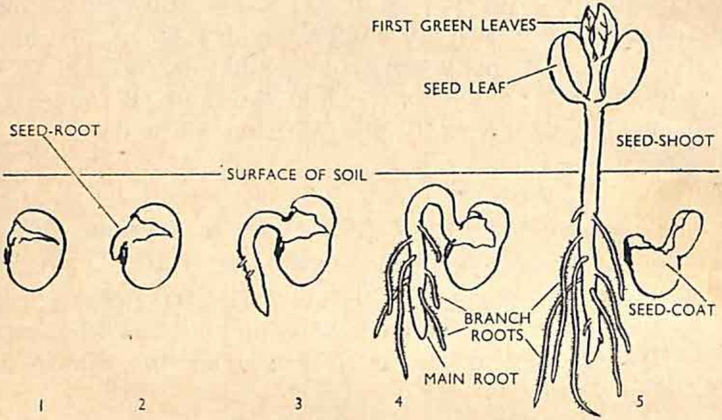


FIG. 28. Germination of bean.

HOW MAIZE GRAINS GERMINATE

In a germinating maize grain, the seed-root comes out first and grows downwards (see Fig. 29). Then the pointed seed-shoot breaks through, covered and protected with a white tube (which is part of the seed-leaf) as it forces its way upwards through the soil. When it reaches the surface, the first green leaf breaks through the covering tube and unrolls itself. Other roots soon appear that are not branches of the main root (as in the bean) but which start from the seed itself at the bottom of the seed-shoot. After a few days, these roots become as long as the first root. As the seedling grows, the grain becomes softer and gets smaller and smaller as the food material is used up.

Watch the germination of other seeds, at home, for yourself.

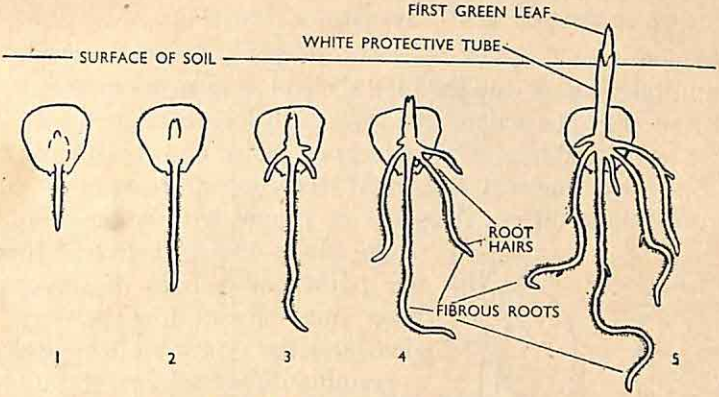


FIG. 29. Germination of maize.

THE TWO GREAT GROUPS OF FLOWERING PLANTS—MONO-COTYLEDONS AND DI-COTYLEDONS

If we examine the seeds and seedlings of many different kinds of flowering plants we find that they all contain a *seed-plant* and a store of food that is used up by the seedling as it grows, until it has liberated itself from its seed-coat and has produced green leaves. Although every seed and seedling has to do the same sort of thing, they do not all do it in the same way. Some seeds have *only one seed-leaf*, e.g. Maize, Rice† (in fact, any 'grain'), palms,† and grasses. *These plants with only one seed-leaf are called Mono-cotyledons.*† Such plants always have *fibrous* roots*, all growing from the bottom of the stem and all of about the same length and thickness, and they have leaves in which the main veins run parallel* to one another. Other plants, whose seeds have *two seed-leaves, are called Di-cotyledons,*† e.g. Bean, Pea,† Balsam, Squash,† Sunflower.† Such plants usually have a *main root* from which grow smaller branch-roots, and their leaves have veins that are not parallel but which form a network, i.e. they have *net-veined* leaves. All flowering plants belong to one of these two main groups.

GROWTH

WHICH PART OF THE ROOT GROWS IN LENGTH?

We have seen that the seed-root always grows downwards into the soil, pushing its way through the soil as it grows in length. We shall now find just where this growth in length takes place. Germinate some seeds (e.g. Cow-peas) in a roll of damp cloth and then pick out a seedling with a straight seed-root. Starting at the tip of the root, mark off equal spaces of 1 mm. with water-proof ink (using a loop of thread stretched across the points of a pair of forceps*).[1] Now put the seedling between the glass and the damp blotting-paper of a germination-vessel and examine it after a few hours.

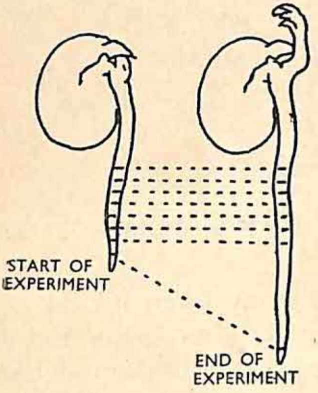


FIG. 30. Growing region of root

What do you notice as the root grows?.........................

....

....

Which marks become wider apart?

....

....

....

Hence, *all the growth in length of a root takes place close behind the root-tip*, as shown in Fig. 30. This is, of course, the best place for the root to apply its pushing force, just where it will force the root-tip through the soil.

(If you wanted to push a long, thin stick into the soil, whereabouts would you hold it?..............................

....)

---

[1] Another method is to draw out a fine thread of black paint (e.g. Brunswick black†) between two pins and then lay it across the root.

WHICH PART OF THE STEM GROWS IN LENGTH?

We can find out where growth takes place in the stem in the same way. Mark off the main stem of a rapidly growing seedling with water-proof ink or oil-paint, putting the marks 5 mm. apart, and examine it after a few hours.

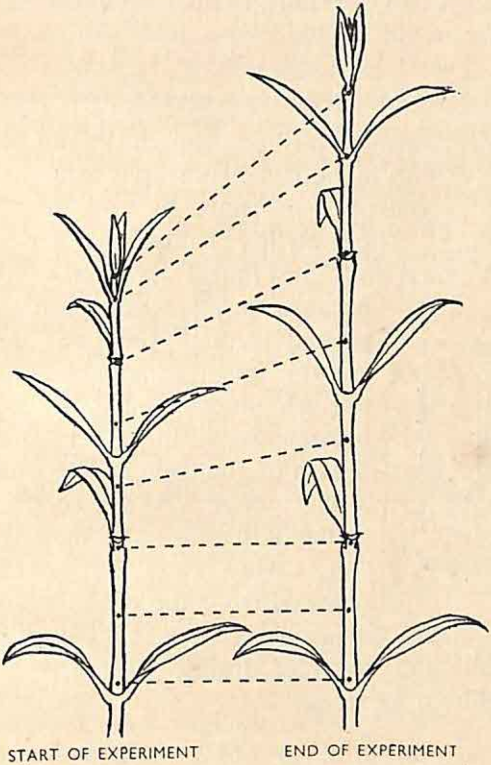


FIG. 31. Growing region of stem.

What do you notice as the stem grows? ....

....

Which marks have become wider apart?..................

....

Hence, *growth in stems is spread over a considerable length of the young stem*, as shown in Fig. 31, and is not limited to a very short region just behind the tip, as in roots. The stem, unlike the root, does not meet with any resistance as it grows in length through the air, and growth is not limited to one small region.

HOW IS THE DELICATE TIP OF THE ROOT PROTECTED?

As the tip of the root is pushed through the soil, the outer layer gets worn away. If an undamaged root-tip is examined with a lens, we find that the root-tip is protected by a *root-cap*,† usually less than 1 mm. long. The root-tips of floating water-plants and the air-roots of Orchids† and Screw Pines† show well-marked root-caps because they are not worn away by being pushed through soil (see Fig. 32). Roots growing in soil usually have their root-caps rubbed smooth, and the root-cap can only be seen by cutting a very thin slice* from the tip of the root and examining it under a microscope.* As the root forces its way through the soil, the outside of the root-cap is worn away, but it is always being renewed from the *growing-point* inside, just behind the root-tip. Growing roots exert* a considerable force, e.g. brick walls and concrete drains* are often split apart by roots of neighbouring trees.

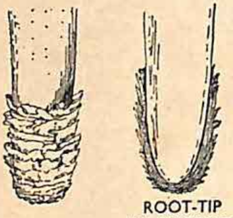


FIG. 32. Root-cap of Screw Pine.

WHAT IS THE DIRECTION OF GROWTH IN ROOTS AND STEMS?

We have seen that in whatever position the seed is planted, the main root always grows downwards and the main stem always grows upwards. In each case the direction of growth is the result of the *force of gravity*,† i.e. the pull of the Earth (see p. 144).

Let some seeds (e.g. Cow-peas) germinate in a roll of damp cloth, and then pick out a seedling with a nearly straight root and stem. Pin it to the cork of a gas-jar or large test-tube lined with damp blotting-paper so that it is horizontal, as shown in Fig. 33. Put the vessel in a dark place and look at it every hour.

Which part of the root turns down? ....

In this experiment, the root gets no light, so it cannot be said that it is merely turning away from the light. Also, since the vessel is lined on all sides with damp blotting-paper, it cannot be said that the root is merely turning towards water. The only force that has acted on the root only from below is the force of *gravity*.

In the last experiment, it is also seen that the main stem turns upwards and thus brings the terminal bud into a vertical position again. It is also seen that the region in which the stem begins to *bend* upwards is some distance behind the tip. In fact, it is the same region as that in which the stem grows in length. (Just as the growing-point of the root is the region that responds* to the force of gravity.) As the seedling was kept in the dark and was equally damp on all sides, the stem must be growing upwards because of gravity. Hence, *the force of gravity directs the growth of the main stem upwards and the growth of the main root downwards.*

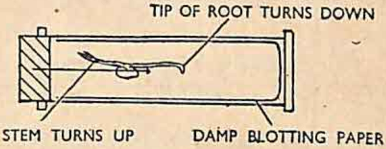


FIG. 33. Effect of gravity on direction of growth.

An influence such as gravity, which acts on a living thing so as to produce some change in it, is called a *stimulus.** The change which the living thing shows is called its *response** to the stimulus. This *response to changes* in their surroundings is another characteristic property of living things which we shall discuss in more detail in Book Four.

HOW DO PLANTS RESPOND TO THE STIMULUS OF LIGHT?

We have all noticed that when plants are kept in a room near a window they bend their main stems towards the window and spread out their leaves to the light. This effect of light on the direction of growth can be shown very clearly by the following experiment:—

A piece of coarse cloth is stretched across the mouth of a glass vessel and is kept damp by hanging one end of the cloth in the water inside the vessel. Small seeds (e.g. Cow-pea or Cress†) are put on the damp cloth, and the vessel is put inside a light-tight box provided with a small hole in one of its sides as shown in Fig. 34. When the seeds germinate, it is seen that the main stems grow straight towards the hole, i.e. *the main stem bends towards the light*, while the roots grow in the opposite direction, i.e. *exposed main roots bend away from the light*. The green leaves grow at right-angles to the direction of the rays of light, thus receiving as much light as possible.

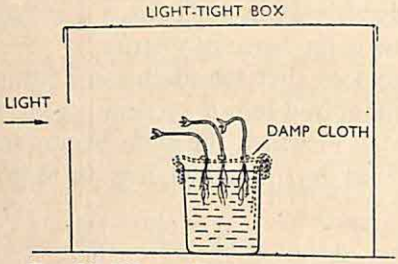


FIG. 34. Effect of light on direction of growth.

WHAT IS THE GENERAL EFFECT OF LIGHT ON PLANT GROWTH?

A few seeds (e.g. Sword-bean† or Cow-pea) are planted in damp soil in two similar pots. One pot is put inside a dark cupboard and the other is kept outside. After about a week, when we compare the seedlings that have grown in the light with those grown in the dark, we see some striking differences (see Fig. 35).

(i) There is a very big difference in *colour*. The seedlings grown in the dark are *white* or *yellow*, while those grown in the light are *green*. Hence, *the green colour of plants is only formed in daylight*. If the white seedlings are taken out of the dark they begin to turn green after a few hours in the light.

(ii) There is also a big difference between the size of the leaves of seedlings grown in the dark and of those grown in the light. The seedlings grown in the dark have only a few very small yellow leaves which often stay folded up, while the seedlings grown in the light have much larger green leaves which are well spread out.

(iii) A plant grown in the dark has a much longer and thinner stem than a similar plant grown in the light.

It is easy to see why there should be such big differences between plants grown in the dark and those grown in the light. In the dark, a long, thin stem helps the plant to reach light as quickly as possible. Also, leaves are of no use to the plant unless they are in the light, so a plant growing in the dark does not grow leaves that would be useless. Once the stem has reached the light, the leaves begin to grow rapidly and they soon turn green.

The direction of growth of leaves is also affected by light, and they usually grow so that the light falls directly on their upper surface. For example, if a plant is kept inside a room, near a window, the leaves soon turn and put themselves at right-angles to the direction of the rays of light. *The main 'need' of a green leaf is to get enough light.*

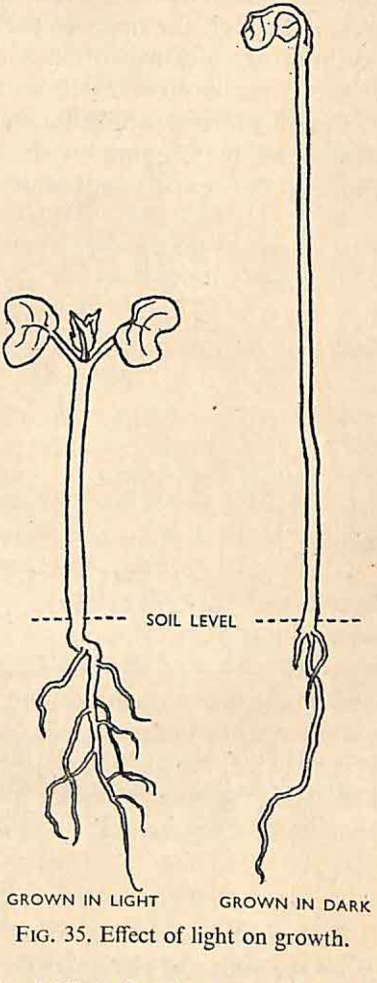


FIG. 35. Effect of light on growth.

WHAT IS THE EFFECT OF WATER ON THE DIRECTION OF GROWTH OF ROOTS?

The roots of a plant are always attracted by water. This attraction can be shown by the following experiment:—Small seeds are sown in damp sawdust on a coarse sieve [1] which is fixed at an angle, the whole being covered with a large jar or tin so that the air inside is kept damp. When the seeds germinate, their roots grow downwards through the holes in the sieve, because of gravity, and they go on growing downwards as long as the surrounding air is damp. If the cover is now raised so as to let in drier air, the roots are attracted more strongly by the water in the damp sawdust, and they bend back again to the bottom of the sieve, as shown in Fig. 36. This experiment shows clearly that *the effect of water on the direction of growth of the root may be greater than that of gravity*. (Repeat the experiment, keeping the apparatus *in the dark*, to find whether light is making the roots turn upwards.)

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[1] Preferably one made of horse-hair or nylon† thread, since metals like copper and zinc (and, therefore, brass) are poisonous to young roots.

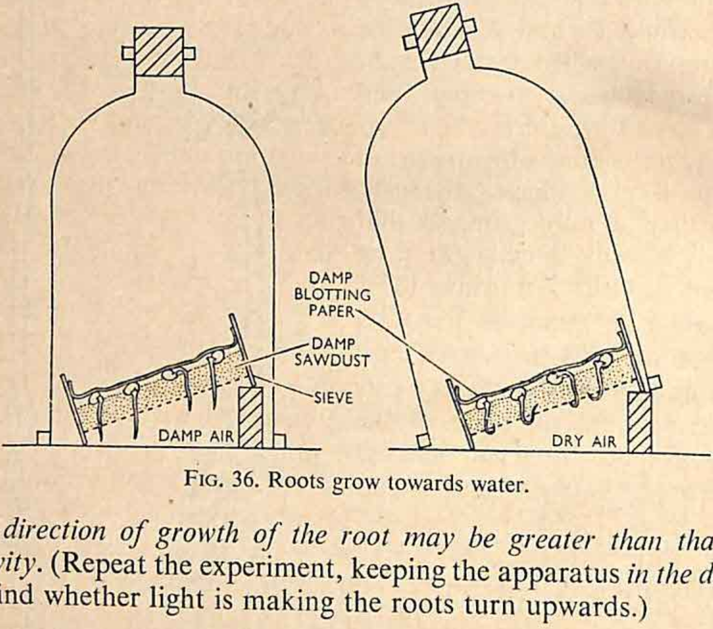

FIG. 36. Roots grow towards water.

ROOTS

The root (i) *takes in water containing dissolved mineral matter from the soil*, and (ii) *holds the plant firmly in the ground*. We have seen that the seed-root is always the first part of the seed-plant to grow out from the seed, and it begins to supply the young plant with water. (It already has a supply of *food* in its seed-leaves.) We know that if we cut off a stem or branch and put the cut end in water, it will live for a few days, but it is only the roots that can supply the plant with water for a long time.

HOW DO ROOTS ABSORB WATER?

Plants produce large numbers of branch roots and still smaller *rootlets* that spread out in every direction through the soil. A little way behind the tips of all these fine rootlets are found large numbers of very fine hairs, called *root-hairs.*[1] We can see these most easily on Cress seedlings that have been grown in a closed box on damp blotting paper (see Fig. 37A and B), but we must remember that these hairs are abnormally straight and free from soil particles. Although the *young* root can absorb water over its whole surface, the root-hairs are extremely important since it is through the very large surface of these hairs that most of the water and dissolved substances pass into the root.

Examine a few fresh Cress seedlings on a dry watch-glass under a lens and notice that it is the root-hair region which loses water most rapidly to the air, because there is no waterproof layer over this region as there is over the rest of the plant.

There are no root-hairs for about 1 cm. back from the root-tip. Then, for a distance of several centimetres, they are found in great numbers. The hairs live only for a limited time, and when they die the part of the root that produced them becomes waterproof. New hairs grow out from the newly formed root behind the tip. Notice that the hairs are produced *just behind the growing root-tip*, where they will not be torn off as the root grows in length. Under the microscope each root-hair is seen to be a narrow tube growing out from a surface cell (see Fig. 37D).

The outer surface of the root-hair is sticky and it attaches itself to the moist* soil grains (see Fig. 37E). Hence the root-hair remains in contact with moisture* even when the soil appears to be dry. If we uproot a seedling and wash away the soil from the root under a tap, we cannot remove all the soil without tearing off most of the root-hairs at the same time.

---

[1] Pea seedlings have about 200 root-hairs per square millimetre of root surface.. Maize seedlings have even more root-hairs than this.

When a plant is dug up and moved to a new place (or *transplanted**) it often wilts* for several days and it begins to look healthy and to grow again only when a new set of root-hairs has been produced, to replace those damaged by transplanting.

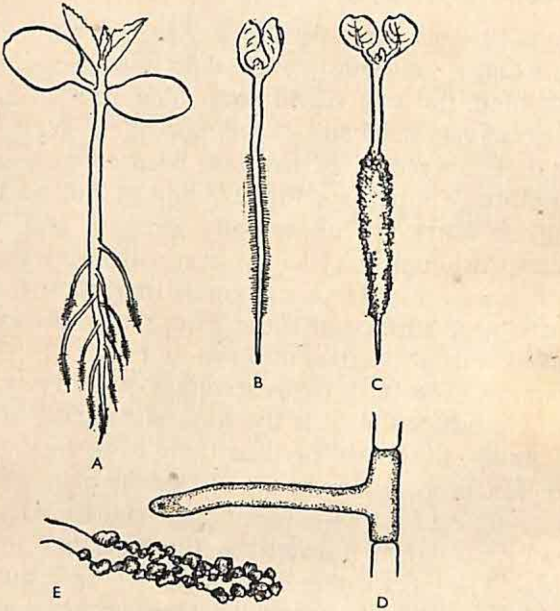

FIG. 37. Root hairs.

A. Seedling showing root-hair regions.
B. Cress seedling grown on damp paper.
C. Cress seedling grown in soil, with soil particles sticking to the root-hairs.
D. Part of B, magnified to show a single root-hair cell.
E. Single root-hair attached to soil particles (highly magnified).

Only water and dissolved substances can enter the root: solid particles, however small, cannot enter. This can be shown by the following experiment:—Take two jars of water and colour one of them with a little red ink, which is a red dye *dissolved* in water. Colour the other one red with carmine,† an *insoluble* colouring matter which remains *suspended* in the water as very fine solid particles. Dig up two white-flowered Balsam plants, damaging their roots as little as possible, and put one of them in each jar. Next day, the plant in the red ink *solution* is found to be stained with red inside the root and stem, while the white flowers are also red round their edges. The plant in the carmine *suspension*, however, shows no trace of red in its root, stem, or flowers. This experiment shows, therefore, that *only dissolved substances can enter the root: solid particles, however small, cannot enter*.

We must now find out how water and dissolved substances enter the root-hairs although they are tiny closed tubes without any openings in their walls.

OSMOSIS AND OSMOTIC PRESSURE

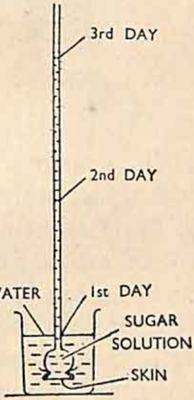

FIG. 38. Osmosis.

Water and dissolved substances enter the root-hairs by a physical process called *osmosis*.† In this process, if a concentrated solution is put on one side of a thin skin, and a dilute solution is put on the other side, the two solutions gradually become of the same concentration. The following experiment shows what happens in this process:—

A piece of skin[1] is tied tightly over the wide end of a thistle-funnel† and the bulb of the funnel is then filled with a concentrated solution of sugar. The thistle-funnel is supported in a beaker of water as shown in Fig. 38, and the level of the sugar solution inside the thistle-funnel is marked with a strip of gummed paper or a small rubber band. In a short time the level of the sugar solution begins to rise and goes on rising, day by day, until the pressure exerted by the column* of water in the tube may become great enough to burst the skin. The height of this column of water measures the *osmotic pressure*† of the sugar solution.

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[1] Bladder,† 'cellophane',† or parchment-paper† may be used; old drum-heads of sheep-skin are excellent.

This osmotic pressure is produced by water passing from the beaker through the skin into the sugar solution. (A little sugar passes in the opposite direction at the same time.) Root-hairs take in water from the soil in just the same way, since the *sap*,* or liquid inside the root-hairs, is a more concentrated solution than the soil-water outside. If the soil-water contains too much dissolved matter, osmosis may take place in the opposite direction, and water passes outwards from the root-hairs, thus making the plant '*wilt*' (i.e. the green parts of the plant become soft and hang down). In the above experiment, the thistle-funnel and skin, containing sugar solution, form an enlarged 'working model' of a root-hair, and the water in the beaker represents the soil-water.

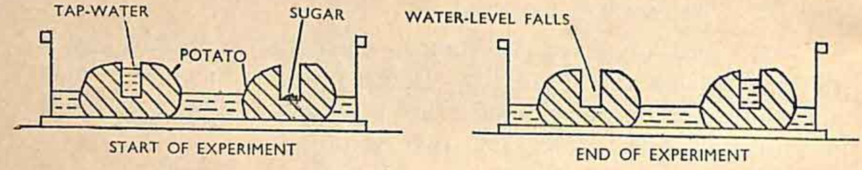


FIG. 39. Another experiment to show osmosis.

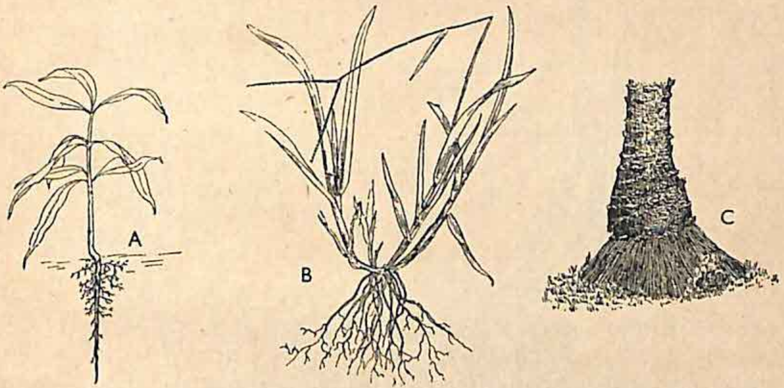
Another simple experiment will show that osmosis takes place in *living* plant material. Take two similar English potatoes† and cut off a slice from one end of each so as to form a flat base for it to stand on. Remove a ring of skin (about 1 in. wide) round the base of each potato, and then make a round hole in the top of each, down to about an inch from the base, as shown in Fig 39 (making the hole with a large cork-borer*). Stand the potatoes in a dish containing a little water; put a few grams of sugar in the hole of one potato, and half-fill the hole in the other potato with tap-water.

In a short time the sugar absorbs enough water to form a solution, and the volume of this solution gradually increases as water enters by osmosis through the potato. In the other potato, the water-level falls because there is no concentrated solution inside.

We shall learn more about osmosis in Book Four.

OTHER WORK OF ROOTS

Besides taking in water containing dissolved mineral* matter from the soil, roots also hold the plant firmly in the ground, or, in the case of some *climbing plants* (e.g. Vanilla† and some other Orchids), to other supports. We have seen that the roots branch and spread in all directions through the soil to get water, and that this branching and spreading also serves to hold the plant firmly in the soil.



A Tap-root of Mango seedling B Fibrous roots of grass C Fibrous roots of Palm

FIG. 40. Different kinds of roots.

TAP-ROOTS AND FIBROUS ROOTS

The roots of the plants we have studied have been of two kinds. In *Di-cotyledons* (e.g. Cow-pea, Mango,† Cotton,† Orange,† Lime†) the first root to appear grows straight downwards and is much bigger than the branch-roots which appear later. A main root of this kind is called a *tap-root*,† and this is characteristic of plants whose seeds have *two* seed-leaves (see Fig. 40A). In *Monocotyledons* (e.g. Maize, Rice, Millet,† Bamboo,† and all palms and grasses) all the roots are quite thin and all about the same size. Such roots are called *fibrous roots*, and they usually grow only in the top layer of the soil, whereas tap-roots make their way deep down into the soil (see Fig. 40B and C).

ROOTS THAT GROW ABOVE THE GROUND

Most roots start from the bottom of the stem and grow down through the soil, but some plants send out roots *above* the ground. For example, some plants form *buttress* roots*, which are partly stems and partly roots, and these support the main stems more firmly. Examples of plants with buttress roots are Ceiba† (Silk-cotton†............),[1] Poinciana† (Flame Tree†............), Ficus elastica† (Indian Rubber-tree†),[2] Terminalia† (Indian Almond†......................). These buttress roots are usually produced by trees whose roots do not go deep down into the ground (see Fig. 41).

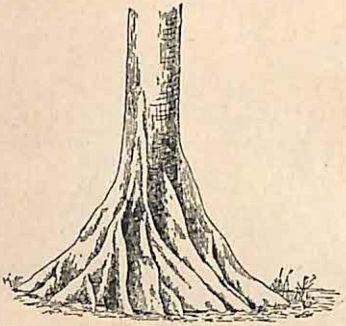


FIG. 41. Buttress roots of Silk-Cotton.

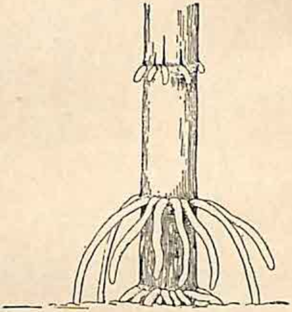


FIG. 42. Prop-roots of Maize.

Maize sends out *prop-roots*† from its stem, a little way above the surface of the soil (see Fig. 42) Screw-Pine† (............) has similar prop-roots growing from its stem, while the Banyan†

---

[1] Write in the local name on the dotted line.

[2] This is *not* the Para Rubber-tree.

(............) sends down roots from its branches, and these roots grow into the soil and then support the horizontal branches.

One kind of Mangrove† tree (Rhizophora†................) grows in deep, soft mud and the main stem is supported by roots that grow outwards and downwards to form *prop-roots*. Another kind of Mangrove (Bruguiera† ....) has buttress roots and no prop-roots, but there are also *breathing-roots*, sticking up out of the mud (which contains very little oxygen).

Some Orchids that grow high up on trees in tropical forests have long, hanging *air-roots*† which absorb the rain that falls on them. We shall refer later to roots that help plants to climb.

STORAGE ROOTS†

Some plants have enlarged roots for storing reserves of food (see Fig. 43). The roots of Tapioca† (Cassava†............), Sweet Potato, Carrot† (..............), Beetroot† (..........), Turnip† (..............), and Radish† (..............) are very much swollen, and they contain large quantities of food, usually *starch*, but sometimes *sugar*. These reserves of food are often used by Man and other animals for their own food: in fact, it is very fortunate for animals that plants nearly always make more food than they use themselves.

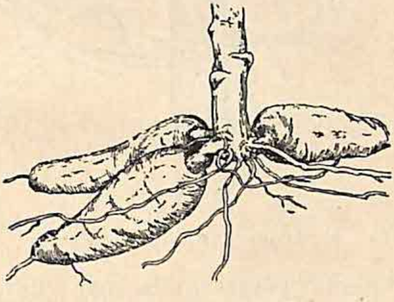


FIG. 43. Storage roots of Cassava.

The main work of stems is

(*a*) *to hold the leaves in the best position for receiving light* (and, sometimes, to display the flowers),

(*b*) *to carry water, containing dissolved mineral matter, from the roots up to the leaves*, and

(*c*) *to carry manufactured food-stuffs downwards from the leaves to other parts of the plant.*

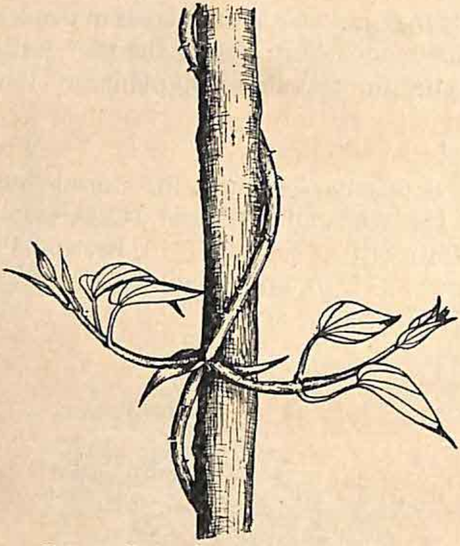


FIG. 44. Twining stem of Yam-bean.

The stems of different plants are of many different kinds, sizes and shapes. Most plants, e.g. trees, have an *upright stem* holding the leaves above the surrounding plants where they are not shaded. In forest and jungle* there is very fierce competition for *light*, each tree struggling upwards to reach the light above the forest roof.

A plant is usually surrounded by its raw food-materials—air containing a little carbon dioxide surrounds its leaves, and the soil around its roots contains water and mineral salts. In later lessons you will see that, in spite of this, plants often have to struggle to get enough light.

If an upright stem is to grow tall it must be strong, but many plants which have only weak, thin stems raise their leaves to the light by taking hold of stronger plant stems or other supports. Such plants are called *climbing plants*, and the commonest ways in which weak stems climb are (*a*) by *twining*,* (*b*) by *tendrils*,† (*c*) by *thorns*† and *hooks*, and (*d*) by *roots*.

HOW PLANTS CLIMB BY TWINING

Plants like Morning Glory† (..............), Yams† (.............), and many kinds of beans, twist their stems round other plants or supports and climb in this way. The tip of the young stem first bends to one side and then begins to swing slowly round in a circle until it touches something solid. The outer part of the stem then grows more rapidly than the inside, so that the stem twists round and round in a spiral, clinging tightly to the support (see Fig. 44).

HOW PLANTS CLIMB BY MEANS OF TENDRILS

Many plants produce tendrils which cling to supports, e.g. Squash (Pumpkin†..............), Cucumber† (............), Melon† (..............), Antigonon† (Honolulu................), Gloriosa† (Climbing Lily†................), and Passion Flower† (.................). Branch-stems, leaf-stalks, and sometimes leaf-tips, grow into long, thin, whip-like tendrils, which swing slowly round and round until they touch a support. The end of the tendril then twists itself round the support. The rest of the tendril afterwards twists to form a spring that stretches when the plant is blown by the wind and recovers when the pressure is relieved. As

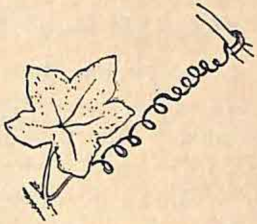


FIG. 45. Tendril of Cucumber.

both ends of attached tendrils are fixed, the spiral 'springs' have an equal number of left-hand and right-hand turns (see Fig. 45). In Gloriosa, the leaf-tips form tendrils (see Fig. 46A). In Clematis† (............) the leaf-stalks twist round the support (see Fig. 46B).

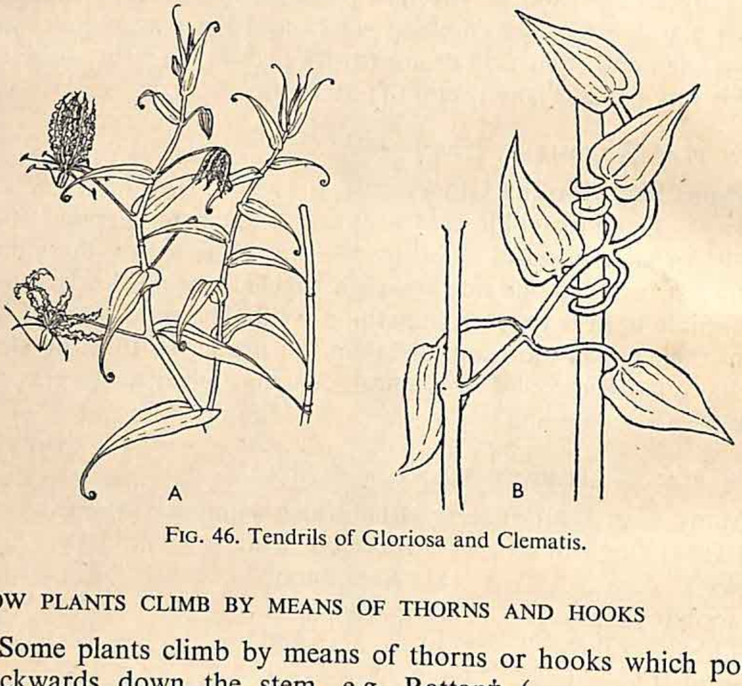


Fig. 46. Tendrils of Gloriosa and Clematis.

HOW PLANTS CLIMB BY MEANS OF THORNS AND HOOKS

Some plants climb by means of thorns or hooks which point backwards down the stem, e.g. Rattan† (................), Mimosa† (Sensitive Plant† ....), Lantana† (.............), and Bougainvillea† (..............). As the stem grows upwards, these backward-pointing hooks slide forward and catch on supports so that the stem cannot slip back again. This is a more uncertain method of climbing than by twining or by tendrils, and these plants may be called '*scramblers*'* rather than 'climbers' (see Fig. 47).

HOW PLANTS CLIMB BY MEANS OF ROOTS

Some climbing plants, e.g. Vanilla and some other Orchids, Pepper† (..............), put out *air-roots* from their stems, and these roots wrap themselves round the stems of other plants or fix themselves in holes and cracks, thus enabling the plant to climb and expose its leaves to the light (see Fig. 48). Climbing plants with *clasping*-roots* are often seen on the trunks of trees in tropical forests (see Fig. 49). Some root-climbers go even farther and get food as well as support from other plants, e.g. Loranthus† (Mistletoe†..............), Cuscuta† (Dodder†..............), and Cassytha† (..............). Such plants are called *parasites*.†

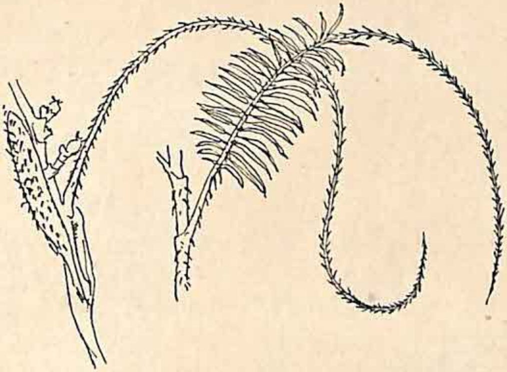


FIG. 47. Thorns of Rattan.

CREEPING STEMS

The stems of some plants, e.g. many grasses, neither grow upright nor climb up supports, but simply lie on the ground. They can only do this successfully where they are not shaded by other plants, hence plants with *creeping stems* are commonest on open waste land and on the sea-shore. Some of these creeping plants produce new plants at intervals,* so that a number of plants may be joined together by horizontal stems, or *runners*.† Sweet Potato† (..............), Carpet Grass† (..............), Spinifex†

(..............), and Hydrocotyle† (..............) have creeping stems of this kind (see Fig. 50). If the connecting runner is cut or broken, the new plants can live independently. Plants

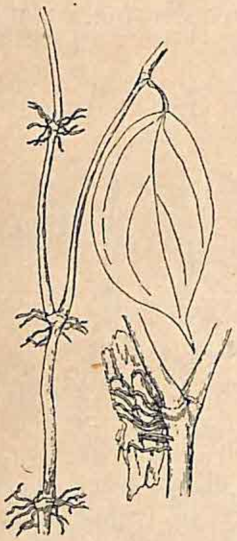


FIG. 48. Clasping-roots of Pepper-vine.

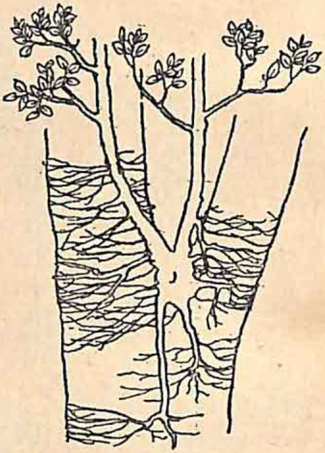


FIG. 49. Clasping-roots of Ficus.

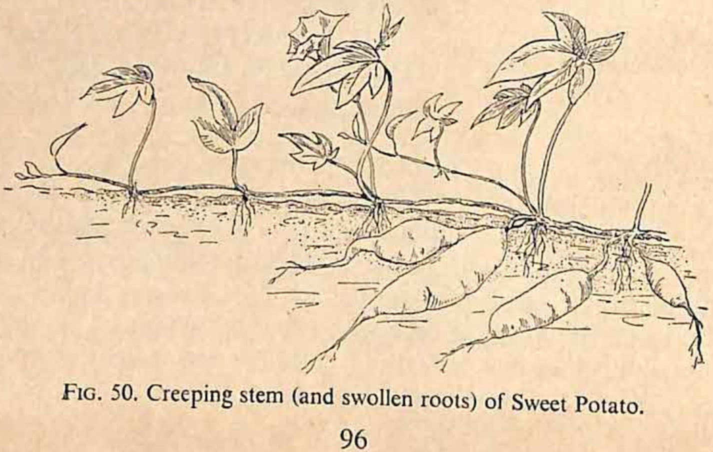


FIG. 50. Creeping stem (and swollen roots) of Sweet Potato.

with creeping stems are often used as *cover-crops*† since they form a thick mass of stems and leaves completely covering the soil, e.g. Centrosema† (............) and Calopogonium†(....................). We shall learn more about cover-crops in Book Two.

Many creeping stems, however, only lie on the ground if they can find nothing up which to climb, e.g. plants of the Sweet Potato and Squash families, Centrosema and Calopogonium will climb upwards if they can find any suitable support, otherwise they creep along the ground.

UNDERGROUND STEMS

Some plants have stems that grow below the surface of the soil and which look very much like roots. To tell an *underground stem* from a true *root*, you must remember that a stem bears *leaves* and *buds* of some kind while *roots never bear leaves*. In most cases, however, the leaves on underground *stems* are very small, merely tiny scales, which are white, yellow, or brown in colour.

Most underground stems store up plant food, usually *starch*, but sometimes *sugar*, and many plants can be grown from a piece of underground stem more easily than from seeds. This is called *vegetative* reproduction*,† which we shall study in more detail in Book Four.

Underground stems can be divided into several different classes: —(*a*) *bulbs*,† (*b*) *corms*,† (*c*) *rootstocks*† (or *rhizomes*†), (*d*) *tubers*,† and (*e*) *suckers*.†

BULBS

Common examples of bulbs are Onion† (..............), Lily† (...............), and Crinum† (...............). A bulb is simply a large *underground bud*, consisting of a much shortened stem covered with thick, fleshy scale-like leaves full of food. The roots all grow from the bottom of the bulb and the new plant grows from the middle of the bulb (see Fig. 51). When a bulb is planted, it produces a new plant much more quickly than when a seed is sown, since the bulb contains so much more food than the seed.

If a lily bulb is planted in damp soil, the first thing to appear above the ground is the flower-stalk, followed later by leaves.

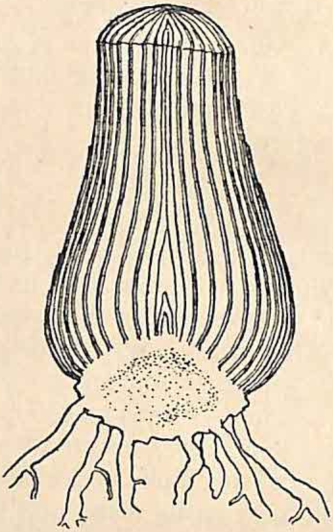


FIG. 51. Section of bulb of Crinum lily.

When all the food in the bulb has been used up, the green leaves manufacture more food, which is stored up in a new bulb that can survive* a dry or cold season and then start growing once more when conditions become favourable.

CORMS

Another kind of thickened underground stem is the *corm*. When cut across, a corm is seen to have a solid centre covered with *thin* scales which contain no reserve of food (unlike the thick, fleshy scales of a bulb). Buds grow round the top and sides of the old corm and develop into new corms which can produce new plants (see Fig. 52). Examples of plants that reproduce by corms are

Gloriosa, Colocasia† (Coco-yam†............), and Xanthosoma† (Tania†................).

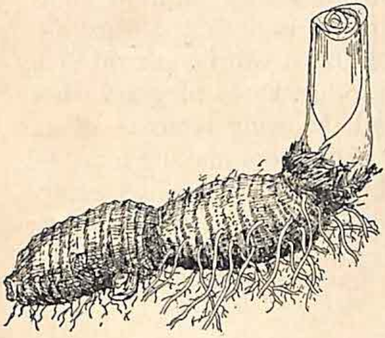


FIG. 52. Underground stem (corm) of Coco-yam.

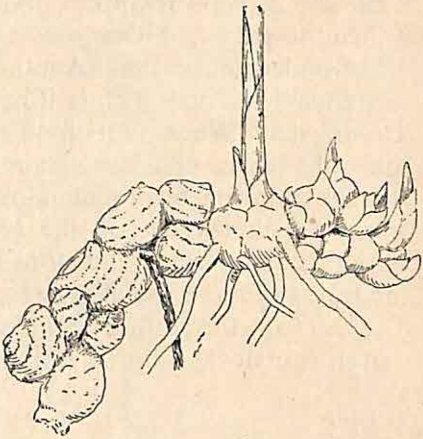


FIG. 53. Underground stem (rhizome) of Ginger.

ROOTSTOCKS

Examples of plants with rootstocks (or rhizomes) are Arrowroot† (..............), Ginger† (..............), Canna† (..............), Water Lily† (..............), Ferns† (..............), and Imperata† (Lalang†..............). These plants have thickened underground stems running almost horizontally below the surface of the soil and bearing scale-leaves, buds, and roots (see Fig. 53). The buds on these underground stems form shoots that grow above the ground and bear leaves and flowers. It is easier to grow such plants from a piece of the rootstock than from seeds: in fact, many troublesome *weeds* (i.e. 'plants growing in the wrong place') owe their success to having a rootstock. A good example is Imperata (Lalang grass), which is one of the first weeds to appear on freshly-cleared soil (because its seeds are easily carried by the wind). It soon produces rootstocks running underground in all directions and stores up reserve food in them. If there is a fire or long dry season, most of the other plants are killed, but the underground stems of weeds like Lalang are undamaged and fresh shoots soon re-appear above-ground. Such weeds are very difficult to get rid of. One way is to dig the soil and pick out *every bit* of underground stem. Another way is to cut the Lalang grass at frequent intervals, before it has time to store food in its underground stem. When all its food reserve is used up, the plant dies. Since the leaves of Lalang stand upright, it can be got rid of by frequent mowing* without harming other kinds of grass whose leaves lie almost flat on the ground. Mowing removes *all* the upright Lalang leaves and stops the plant from making food, but the leaves of more useful grasses, lying flat on the ground, escape. The *turf*† on the surface of a playing-field is a thick mat of interwoven rootstocks—horizontal underground grass-stems.

TUBERS

A tuber is a much thickened part of an underground stem in which a plant stores up food. Good examples of tubers are English Potatoes, and some Yams (............................). There do not seem to be any leaves on a potato tuber, but we can see tiny buds which are called the 'eyes' of the potato, with the scar left by a scale-leaf as the 'eyebrow'* (see Fig. 54). If a tuber is planted in damp soil, the 'eyes' send out roots and shoots which form new plants. English potatoes are nearly always grown from tubers in this way; a piece of potato bearing an 'eye' is planted instead of using seeds.

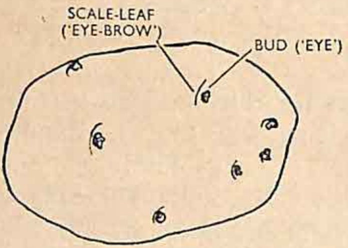


FIG. 54. Tuber of Potato.

SUCKERS

A sucker is a thick, fleshy shoot growing from beneath the soil. either from the base of the stem or from the root. Good examples of plants that form suckers are Bananas† (........................... ....) and Plantains† (................................). Bananas are always grown from *root-suckers* since they seldom produce fertile seeds (see Fig. 55). Pineapples† (............................ ....) produce *stem-suckers* from the base of the stem and these suckers can be removed and planted to produce new plants. Suckers are sometimes called *off-shoots*.

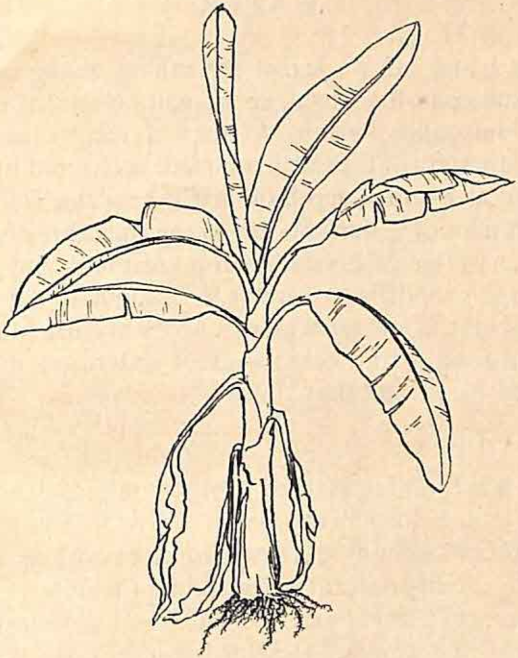


FIG. 55. Complete sucker of Banana plant.

Although it is convenient to classify underground stems in this way, it is often difficult to make clear distinctions, e.g. it is sometimes hard to decide whether an underground part is a corm, or a tuber, or even a storage root.

Learning Exercises on Chapter IV will be found on pp. 5–7 of *General Science Workbook I.*

CHAPTER V

WATER

In Chapters I and III we learnt something about *air*, the commonest substance in the world, so we will now turn to the second commonest substance—*water*. A map of the world shows that about three-quarters of the Earth's surface is covered by seas, lakes, and rivers (to an average depth of nearly 3 miles). The atmosphere also contains a lot of water-vapour. Many rocks are crystalline and contain much water of crystallization. Animals and plants, too, contain a large proportion of water, e.g. about 70 per cent. of our own body-weight is water. Water is necessary for life: men have lived without food for 5 weeks; without water, however, few men have survived for longer than 5 *days*.

NATURAL WATERS

Water, as it is found in Nature, always contains dissolved matter and usually some suspended matter as well. Since water from different sources contains different kinds of foreign matter, it is convenient to classify natural waters under the following headings: (*a*) *Rain-water*, (*b*) *Ground-water* (or *shallow well-water*), (*c*) *Spring-water* (or *deep well-water*), (*d*) *River-water*, and (*e*) *Sea-water*.

RAIN-WATER

Rain, as it begins to fall from the clouds, is almost pure water, but as it falls it dissolves some air and it also carries down any dust (living and non-living) that may be in the air. In other words, rain washes the air, so that rain-water collected at the beginning of a shower contains much more foreign matter than rain-water collected towards the end of a shower. We can show that rain-water contains dissolved air by the experiment shown in Fig. 56.

One bottle contains fresh rain-water and the other contains recently boiled water. The two bottles are connected to an air-pump. As the air above the water in both bottles is pumped out, bubbles form in the rain-water and rise to the surface, but no bubbles are formed in the boiled ('air-free') water.

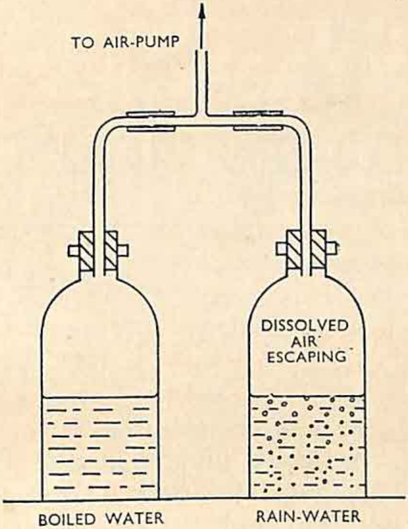


FIG. 56. Liberating dissolved air from rain-water.

SPRING-WATER AND WELL-WATER

During heavy rain, or if the ground is not porous,* most of the rain-water runs off the top as muddy *surface-water*, carrying away suspended soil particles. When the rain is light, or if the ground is porous, the rain-water sinks into the earth and first forms a thin film of water round each soil particle. If the rain continues, the rain-water fills most of the spaces between the soil particles and then filters downwards, dissolving small quantities of *mineral matter* (or *inorganic* matter*), until it comes to a non-porous layer of clay or rock, through which water cannot pass. This *ground-water* then collects to form an underground pool. In hilly places, this ground-water will flow slowly sideways through the ground until it reaches a slope and forms a *spring*. In flat places, the ground-water may be raised from *wells*, which are holes dug deep enough to reach underground pools of ground-water (see Fig. 57). A *shallow well*, or *water-hole*, does not pass through the first non-porous layer. A *deep well* passes through the first non-porous layer to reach deeper pools of ground-water. The water that reaches a shallow well has seldom filtered far through the soil and may therefore be unsafe to drink. Springs and deep wells, however, usually supply good drinking-water because the water has been thoroughly filtered by passing through a considerable depth of earth.

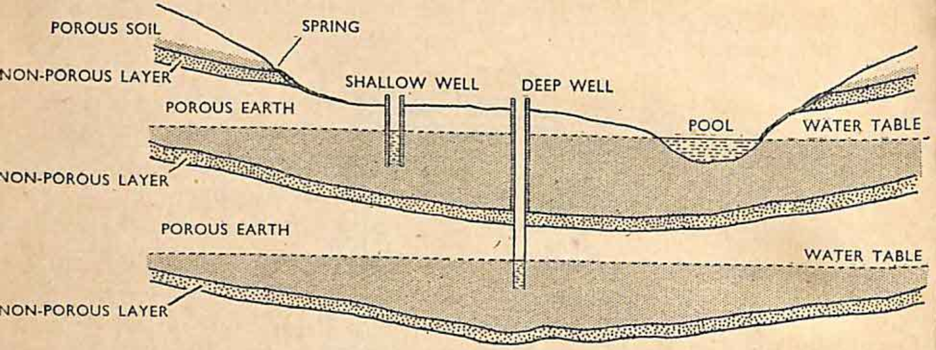


FIG. 57. Water-bearing layers, and wells.

RIVER-WATER

Surface-water and spring-water both flow into rivers, hence river-water contains *both dissolved and suspended matter*. The amount of foreign matter usually increases as the river flows along, especially if it receives drainage* from towns, villages, and cultivated land on its banks. Just as spring- and surface-water flow into rivers, the rivers themselves flow into the sea, carrying dissolved mineral matter and any suspended matter that has not settled to the bottom as the flow of the river becomes slower.

SEA-WATER

When rivers enter the sea, most of the remaining suspended matter falls to the bottom (often forming a 'bar' at the river-mouth), but the dissolved matter remains in the sea-water. Now, water is always evaporating from the surface of the sea, but the water-vapour that rises from the sea by evaporation is *pure water*, containing no dissolved matter. Hence, if the sea is always losing pure water by evaporation and is always receiving dissolved mineral matter from the rivers, then the seas of the world must become more and more 'salty'.

The average amount of dissolved mineral matter in sea-water is about 4 per cent., and more than three-quarters of this is common salt, which gives sea-water its characteristic taste. The other 1 per cent. is composed mainly of compounds of magnesium and calcium. The amount of dissolved mineral matter increases most rapidly in inland seas and lakes where the sun is hot and where evaporation is rapid. For example, the Dead Sea in Palestine contains about 23 per cent. of dissolved substances; but the Baltic Sea, which has less evaporation owing to its colder climate and which is fed with fresh water by many large rivers, contains only about 0·5 per cent. of dissolved matter, i.e. only about one-fiftieth of the amount in the Dead Sea. In fact, the Dead Sea is like a huge evaporating-dish, because salt crystallizes out round the shores as water is evaporated by the sun.

HOW TO EXAMINE SOME NATURAL WATERS

(i) Put a mark (e.g. a rubber band) on a clean test-tube about 2 in. from the bottom. Fill it to this mark with rain-water, pour this water on to a clean watch-glass and heat it gently on a water-bath. When all the water has disappeared, dry the *outside* of the watch-glass and hold it up to the light.

How much dissolved matter does rain-water contain?........

....

(ii) Repeat the experiment with the same quantity of spring-water (or deep well-water).

How much dissolved matter does it contain?. . . . .

. . . .

(iii) Repeat the experiment with the same quantity of river-water, (*a*) without filtering, (*b*) after filtering.

How much dissolved matter does the river-water contain?

. . . .

How much suspended matter does the river-water contain?

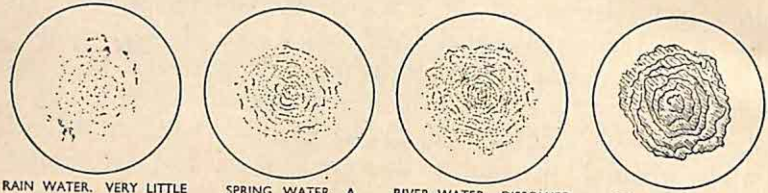
. . . .

(iv) Repeat the experiment with the same quantity of sea-water.

How much dissolved matter does the sea-water contain? . . . .

. . . .

Which is the purest natural water?. . . . .



RAIN WATER. VERY LITTLE DISSOLVED MATTER

SPRING WATER. A LITTLE DISSOLVED MATTER

RIVER WATER. DISSOLVED AND SUSPENDED MATTER

SEA WATER. MUCH DISSOLVED MATTER—SALT

FIG. 58. Residues from natural waters.

THE CIRCULATION OF WATER IN NATURE—THE WATER CYCLE

Water is always evaporating from seas, lakes, and rivers (and also, as we shall see later, from the surface of the soil and from the leaves of plants). Under certain conditions (which we shall discuss in Book Three) the water-vapour in the air condenses to tiny drops of liquid water—so small that they float in the air—thus forming *clouds*. If more water condenses on these tiny drops they become big enough to fall as *rain* (or as *snow* or *hail** in cold countries). This rain-water either runs off as surface-water or it sinks into the ground and appears later as spring-water. In either case it is finally collected by rivers and carried to the sea, where it is evaporated once more, thus repeating the same *cycle* of changes.

A *cycle* is a series* of changes which, in time, brings us back to the starting-point once more, just as a spinning bicycle-wheel brings the valve† back to the same point once in every complete turn. Our work at school, too, is arranged as a weekly cycle of lessons. We do different work on each day of the week, but each Monday we begin a new cycle of lessons and study the same subjects as we did the Monday before, in the same order.

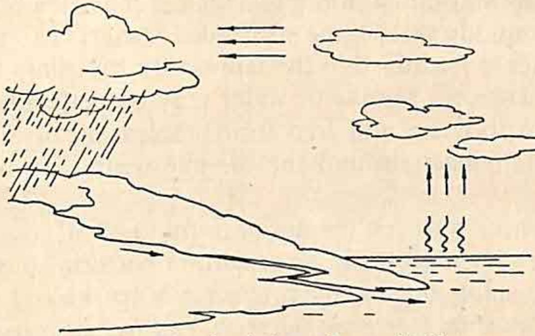


Fig. 59A. The circulation of water in Nature.

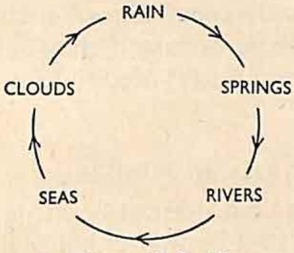


Fig. 59B. The Water Cycle (diagrammatic).

Since all the water in the world is always circulating* through a *cycle of changes*, as shown in Fig. 59A and B, the total amount of water in the world never grows less. (Compare the Water Cycle with the Carbon Cycle, p. 67.)

WHAT ARE THE CHARACTERISTICS OF WATER THAT IS FIT TO DRINK?

The dissolved mineral matter (or *inorganic* matter) in most natural waters is not bad for the health unless it is present in large quantities.

Most natural waters, however, also contain *suspended matter* that must be removed before the water is safe to drink. The most dangerous suspended impurities are *bacteria* (some of which may cause disease), together with the remains of living things (organic* matter) on which bacteria feed. This dangerous suspended organic matter may come from the soil and from sewage.* Although suspended clay and similar inorganic matter can often be seen (e.g. in cloudy or muddy water), the suspended bacteria cannot be seen until the water is examined in the laboratory by using a powerful microscope. Hence a sample of water may be perfectly clear and sparkling* to look at, and free from unpleasant taste or smell, and yet contain bacteria and the organic matter on which they feed.

Most bacteria, however, are not harmful to Man; some, we shall see later, are very useful. But since certain bacteria cause diseases like typhoid,† cholera,† and dysentery,† *any water that is to be used for drinking must be free from bacteria, and free also from organic matter on which bacteria might feed.* In addition to bacteria, natural waters in tropical countries sometimes contain the eggs and young of tiny worms that cause disease if they enter the human body. Hence, nearly all natural waters need to be purified before they are used for drinking.

HOW IS WATER MADE FIT TO DRINK?

(i) Small quantities of water can be made safe for drinking by *boiling*. Boiling for 10–15 minutes kills almost every kind of bacteria that causes disease.

(ii) *Town Supplies.*—It is impossible to boil all the water used in a town. Large supplies of water for drinking and for household purposes may be purified by two main methods:—(*a*) The water is filtered through filter-beds of sand and small stones, as shown in Fig. 60, so that suspended impurities are filtered out. (*b*) The water is treated with some substance that kills bacteria, e.g. *chlorine* (a greenish-yellow gas with a pungent smell) is used for this purpose in many towns. Only small quantities of chlorine are needed, usually about one part of chlorine to every two million parts of water.

For maximum* safety both methods (*a*) and (*b*) are used, one after the other, so as to make quite sure that the water is free from bacteria and contains no organic matter on which bacteria might feed. The water used in modern swimming-pools is usually made safe by the same methods, being continuously circulated through filters and chlorinated.

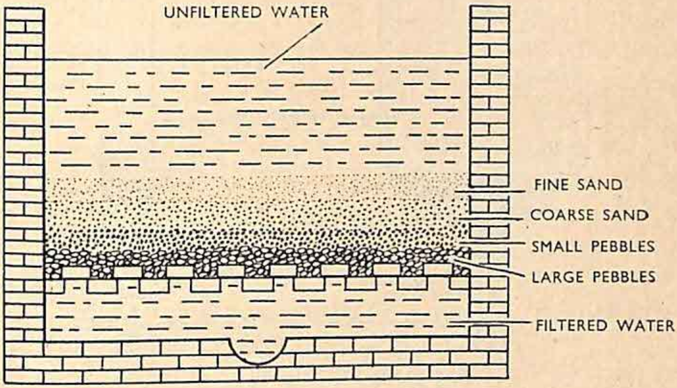


FIG. 60. Slow sand filter.

Set up a model slow sand-filter as shown in Fig. 61, using either an inverted bell-jar (or a large bottle with its bottom cut off) or a wide glass tube. At the bottom put a layer (about 2 in. deep) of pebbles* (about 0·5 in. diameter), then a 2-in. layer of smaller pebbles, then a 2-in. layer of fine gravel,* then a 4-in. layer of fine sand. (A layer of coarsely crushed wood charcoal may be put below the sand to decolorize* brown, peaty* water.) The water should drip *very slowly* from the bottom of the filter, the flow being adjusted* by means of a spring-clip on a piece of rubber tubing, and the model will not work perfectly until the top of the 'filter-bed' has become covered with a layer of slime.* The model filter must not be allowed to dry out between experiments.

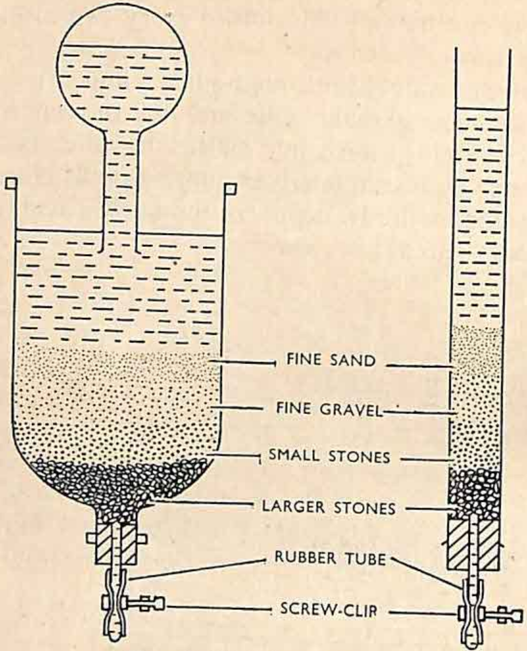


FIG. 61. Model sand filters.

CHEMICALLY PURE WATER—DISTILLED WATER

For some purposes, *chemically pure water* is required, free from all dissolved substances, e.g. for use in the laboratory, for making up medicines, for adding to accumulators† (car batteries†), and sometimes for making ice. Filtering will not remove *dissolved* substances, hence such water is got by *distillation*. In this process, water is boiled and the steam is then caught and condensed. The dissolved substances are not changed into vapour when the water boils, but they remain behind in the boiler. The liquid that condenses is called *distilled water* and it is almost *chemically pure*. (Rain, of course, is natural distilled water, but it is seldom quite pure since it washes the air on its way down to earth.) We shall now imitate the natural processes of evaporation and condensation.

HOW TO OBTAIN PURE WATER FROM SEA-WATER

Fit up the apparatus shown in Fig. 62, and in the boiling-flask put some sea-water which has been coloured with a little ink.

Describe the taste of this water (before colouring it)........

....

Heat the flask and boil the water. When about half the coloured sea-water has boiled away, turn out the burner and examine the liquid that has collected in the other flask.

Describe its taste.................................

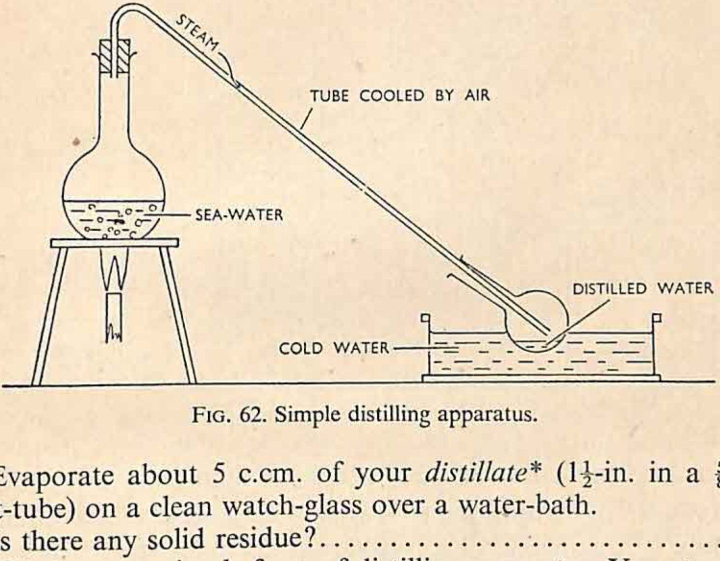


FIG. 62. Simple distilling apparatus.

Evaporate about 5 c.cm. of your *distillate** ($1\frac{1}{2}$-in. in a $\frac{5}{8}$-in. test-tube) on a clean watch-glass over a water-bath.

Is there any solid residue?...............................

This is a very simple form of distilling apparatus. Your teacher will show you a more efficient arrangement in which the steam is condensed as it passes through a tube cooled by water, as shown in Fig. 63.

Distillation is an important process because it enables us to separate mixtures of liquids with different boiling-points, e.g. crude *petroleum*, as it comes out of an oil-well, is a mixture of many different substances which can be separated from one another by *fractional* distillation*. When petroleum is distilled in this way, over 200 commercial products are obtained, all with different boiling-points, e.g. petrol distils off first, then kerosene, then Diesel-oil,† then lubricating* oil, and then petroleum jelly (or vaseline). In many power-stations, all the water to be used in the boilers is distilled. If water containing dissolved mineral matter is used the mineral matter is left behind in the boilers and, in time, spoils them. (We shall learn more about this in Book Two.)

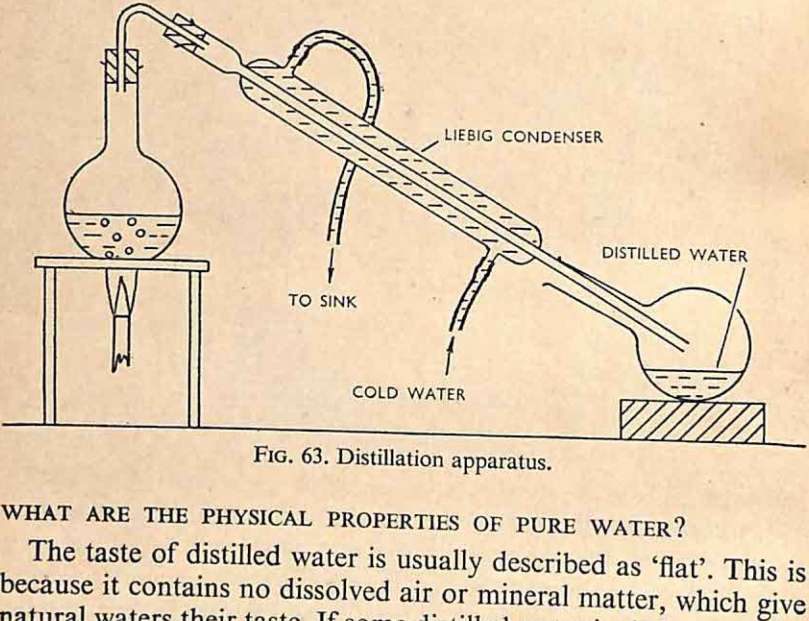


FIG. 63. Distillation apparatus.

WHAT ARE THE PHYSICAL PROPERTIES OF PURE WATER?

The taste of distilled water is usually described as 'flat'. This is because it contains no dissolved air or mineral matter, which give natural waters their taste. If some distilled water is shaken up with air and then tasted, it tastes more like ordinary tap-water.

Pure water is a liquid that has neither colour, nor taste, nor smell. It leaves behind no residue on evaporation. It boils at 100° C. (or 212° F.)[1]*, and freezes to ice at 0° C. (or 32° F.).* 1 c.cm. of pure water weighs 1 gm. (In fact, in the early days of the *Metric System*† the gram weight was the weight of a cubic centimetre of water.) Water is a very good *solvent* and dissolves almost every substance to some extent. (The slight residue left on your watch-glass after evaporating some distilled water had been dissolved from the glass of your distilling apparatus.) This is why it is so difficult to get chemically pure water, quite free from the slightest trace of any dissolved matter.

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[1] On the *Fahrenheit*† scale of temperature (which we shall discuss in Book Three), the melting-point of ice is taken as 32° F. and the boiling-point of water as 212° F.

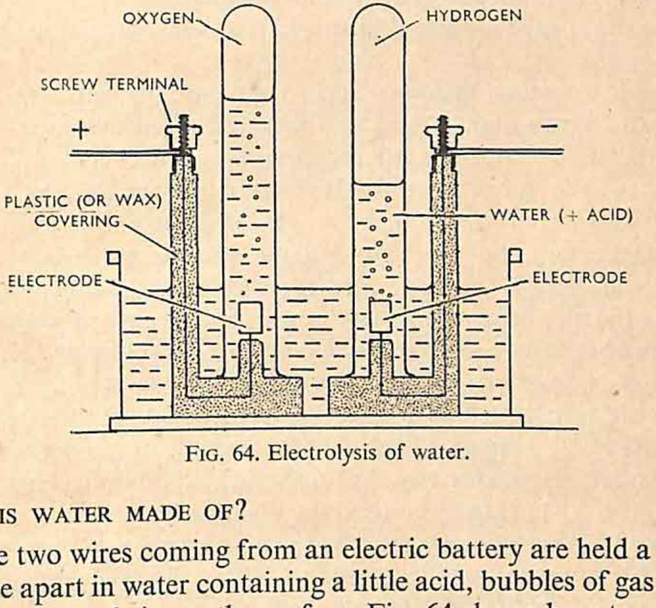

FIG. 64. Electrolysis of water.

WHAT IS WATER MADE OF?

If the two wires coming from an electric battery are held a short distance apart in water containing a little acid, bubbles of gas form on the wires and rise to the surface. Fig. 64 shows how to collect these gases in order to examine their properties and find out what the gases are.

The glass trough is half-filled with water to which a little dilute sulphuric acid has been added. The glass tubes are filled with water and inverted over two small plates of thin metal connected to wires from the battery. (*Platinum* is the metal generally used for these plates since it is not dissolved by the acid or attacked by the gases given off.) When these two platinum plates (or *electrodes*†) are connected to the battery, an electric current passes from one plate to the other through the water. Bubbles of gas form on the electrodes and collect in the two glass tubes. More gas collects in one tube than in the other: in fact, one electrode gives off *twice* as much gas as the other.

On testing the gases in the tubes with a *lighted* wooden splinter, the *smaller* quantity of gas makes the splinter burn much brighter. This gas is therefore *oxygen*. The *larger* quantity of gas catches fire with a slight explosion and burns with a faint blue flame. This gas is *hydrogen*.

These two gases, *hydrogen* and *oxygen*, are liberated from water just as mercury and oxygen are liberated when mercuric oxide is heated, i.e. by splitting up the original substance into its constituents. We have learnt that such a *decomposition* is called *analysis*. But our water-analysis was brought about by using an electric current, hence a good name for the process would be *electro-analysis*. This long word is shortened to *electrolysis*,† and we say that we have *electrolysed* water. By the electrolysis of water we can show that *water is a compound of hydrogen and oxygen in the proportion of two volumes of hydrogen to one volume of oxygen.*

A little sulphuric acid was added to the water in the last experiment to make it *conduct** the electric current, since pure water is a *non-conductor* of electricity. As sulphuric acid contains both hydrogen and oxygen it may be thought that the hydrogen and oxygen collected in the tubes came from the acid and not from the water. That this is not so, is shown by the fact that if a measured quantity of sulphuric acid is added at the beginning of the experiment, the amount of acid does not get less, however long the electrolysis is carried on. (In the same way, an accumulator or motor-car battery never needs more acid, but only more pure water to take the place of the water lost by 'gassing' when the accumulator is fully charged. The bubbles of gas given off by an accumulator during charging consist of two volumes of hydrogen mixed with one volume of oxygen, and as this is an explosive mixture, no flame should be brought near an open accumulator.)

We have now split up water into hydrogen and oxygen (*analysis*). In a later lesson we shall see if we can produce water by making hydrogen combine with oxygen (*synthesis*), i.e. now that we have 'taken water to pieces' we shall try to 'put it together again'. Before doing this, we shall prepare hydrogen in larger quantities and examine its properties.

HYDROGEN

The electrolysis of water is a way of getting hydrogen that is used to manufacture large quantities of hydrogen commercially. In the laboratory, however, it is more convenient to prepare hydrogen by dissolving a metal in either dilute sulphuric acid or dilute hydrochloric acid (but *not* in nitric acid,† which cannot be used for preparing hydrogen).

HOW TO PREPARE A LITTLE HYDROGEN

(i) Add about 5 c.cm. of dilute sulphuric acid ($1\frac{1}{2}$-in. in a $\frac{5}{8}$-in. test-tube) to a small piece of zinc in a test-tube. Notice that bubbles of gas are given off. (If the action is slow, add a few drops of copper sulphate solution to act as a catalyst.) Bring a light near the mouth of the tube and notice that the gas burns with a faint blue flame. (If the gas is mixed with air there will be a slight explosion.) The gas is *hydrogen*.

(ii) Repeat the experiment, using *zinc* and dilute *hydrochloric acid*.

What happens?....................................

(iii) Repeat the experiment, using *iron* filings and dilute *sulphuric* acid.

What happens?....................................

(iv) Repeat the experiment, using *iron* filings and dilute *hydrochloric* acid.

What happens?....................................

(v) Repeat the experiment, using *magnesium* and dilute *sulphuric* acid.

What happens?....................................

(vi) Repeat the experiment, using *magnesium* and dilute *hydrochloric* acid.

What happens?...

HOW TO PREPARE SEVERAL JARS OF HYDROGEN

In the laboratory, hydrogen is usually prepared by treating *zinc* with *dilute sulphuric acid.*

ZINC + SULPHURIC ACID ⟶ ZINC SULPHATE† + HYDROGEN

Use the apparatus shown in Fig. 65. The flask is fitted with a two-hole rubber cork, one hole carrying the delivery-tube and the other carrying a thistle-funnel through which acid is poured on the zinc. *Slide* some small pieces of zinc (about 10 gm.) into the flask and cover it with a test-tube full of water. Add a few c.cm. of copper sulphate solution. What happens?..................

....

....

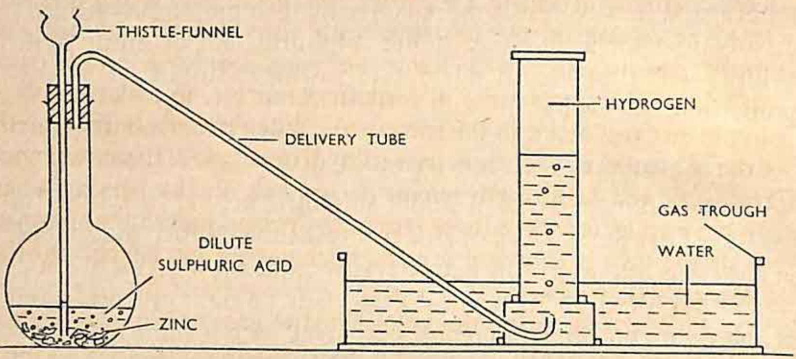

FIG. 65. Preparation of hydrogen.

This will act as a catalyst and make the hydrogen come off more easily.

See that the thistle-funnel has its bottom end dipping below the surface of the water in the flask. Then ask your teacher to approve your apparatus. (*N.B.—There must be no flame on your bench** *while you are preparing hydrogen, otherwise there may be a dangerous explosion.*)

When the teacher has approved your apparatus, pour about 40 c.cm. of dilute sulphuric acid down the thistle-funnel. (N.B.—*Not* the bench reagent, which is too dilute for quick results, but that supplied by your teacher and prepared beforehand by carefully adding one volume of concentrated sulphuric acid to three volumes of water and then cooling.)

After waiting a short time for the air to be displaced from inside the apparatus, invert a test-tube full of water over the end of the delivery-tube and collect a test-tube full of the gas. When it is full, close the mouth of the test-tube with your thumb and bring it, mouth downwards, to a flame *on your teacher's bench.* If it explodes, your apparatus still contains some air, so collect another sample and test again in the same way. When the gas burns quietly in the test-tube, collect three jars of hydrogen, close them with gas-jar covers and keep them *mouth downwards* on the bench. When you have collected these three jars of hydrogen, put your apparatus out of the way before lighting the burner on your bench. Do the following experiments:—

1st Jar.—(*a*) Describe the colour of the gas................

Hydrogen prepared by this method usually contains a strong-smelling impurity, hence you will be unable to describe the smell of *pure* hydrogen at this stage.

(*b*) Hold the mouth of the inverted jar near a flame.

What happens?..............................

Why?....................................

2nd Jar.—Hold the jar, mouth downwards; remove the cover and quickly push a lighted wooden splinter up *inside the jar.*

What happens *to the hydrogen*?........................

....

What happens *to the lighted splinter*?.....................

3rd Jar.—Invert a jar of air over the third jar of hydrogen so that the two jars are mouth-to-mouth. Wrap the inverted jar with a cloth to prevent the glass from flying if it breaks. Remove the cover from between the jars, and after waiting for a second or two, remove the top jar (which originally contained air) and hold it (still wrapped in the cloth) to a flame.

What happens?..

What do you learn from this?............................

....

Now hold the bottom jar to a flame.

What happens? ....

Why?..

....

WHAT ARE THE PROPERTIES OF HYDROGEN?

Pure hydrogen is a gas without colour, taste, or smell. (The hydrogen obtained when commercial zinc, or iron, is dissolved in acids has an unpleasant smell, but the smell is due to an impurity and not to the hydrogen itself.) Hydrogen is the 'lightest' substance known. (Air is over fourteen times 'heavier' than hydrogen.) Hydrogen is only very slightly soluble in water. When a light is put to hydrogen, it burns quietly, with a very faint blue flame, but if air is mixed with it, then the mixture explodes when lighted. Hydrogen will not allow things to burn in it, i.e. it does not support combustion.

Your teacher will demonstrate the extreme 'lightness' of hydrogen by filling a small, thin rubber balloon with *dry* hydrogen. (Two drops of water weigh as much as one litre of hydrogen!). The balloon rises in the air, just as a cork rises to the surface when put under water. Soap bubbles filled with hydrogen will also rise in the air. Compare this with balloons and soap bubbles that have been filled with *air*.

WHAT IS FORMED WHEN HYDROGEN BURNS IN AIR?

In some of our earliest experiments we saw the result of burning candles in jars of air over water. In every case we found that part of the air was used up (the oxygen) and that a *dew* appeared on the inside of the jar. We shall now see what happens when *hydrogen* burns in air.

(*Demonstration.*) Hydrogen prepared in the usual way from zinc and dilute sulphuric acid is dried by passing it through a drying-tube containing fused calcium chloride as shown in Fig. 66. *After making sure that the gas is not mixed with air*, the dry hydrogen is lighted as it comes out of the metal jet.* The flame of the burning hydrogen is then allowed to touch the dry surface of a flask (or a retort†) which is kept cool by running water. (This experiment enables* you to see the colour of the hydrogen flame.) Drops of liquid condense on the outside of the cold flask and can be caught on a watch-glass. The liquid has no colour, taste, or smell. It turns white (anhydrous) copper sulphate blue, therefore it contains *water*. Hence, *water is formed when hydrogen burns in air*.

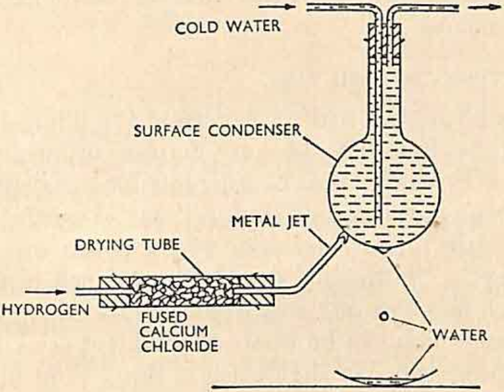

FIG. 66. Burning hydrogen in air.

HYDROGEN + OXYGEN ⇄ HYDROGEN OXIDE† (*water*)

So the chemical name for water is *hydrogen oxide*. The sign ⇄ means that the reaction can go either way, *either*

HYDROGEN + OXYGEN → WATER, *or* WATER → HYDROGEN + OXYGEN

In words, by making hydrogen and oxygen combine together we get water. This is an example of *synthesis*. On the other hand, we can also split up water into hydrogen and oxygen, e.g. by passing through it an electric current. This is an example of *analysis*.

The last experiment explains the formation of dew when a candle is burnt in a jar of air (see pp. 6–7). Candle-wax is a compound containing carbon and hydrogen. The carbon burns to form carbon dioxide, while the hydrogen burns to form hydrogen oxide, i.e. water, which condenses on the glass of the jar. Hydrogen received its name from Lavoisier in 1783, and the word means '*the water producer*'.

WHAT IS HYDROGEN USED FOR?

Since it is so 'light', hydrogen is used for filling balloons and airships, although it has the very serious disadvantage that it catches fire very easily, thus causing terrible accidents. (We have learnt that *helium*, the second 'lightest' gas, is much safer because it will not burn.) The chief uses of hydrogen are in chemical industries, e.g. in 'hardening' liquid *oils* obtained from plants and animals (such as palm oil† and whale oil†) so as to change them into solid *fats* which can be used for food, for cooking purposes, and for making soap. We shall learn in Book Four how hydrogen is used in the manufacture of *ammonia*†. We have already seen that it is used in producing the very hot *oxy-hydrogen* flame (see p. 56).

WHAT HAPPENS WHEN METALS DISSOLVE IN ACIDS?

We have seen that several common metals dissolve in acids, liberating hydrogen. They are said to *displace hydrogen from acids*, the metal taking the place of the hydrogen.

This reminds us of what happens when an iron nail is put in copper sulphate solution (see p. 28).

IRON + COPPER SULPHATE ⟶ COPPER + IRON SULPHATE† (1)

In the same way, when we added copper sulphate solution to zinc before preparing hydrogen (see p. 116), the zinc became coated with copper, *displaced from the copper sulphate*.

ZINC + COPPER SULPHATE ⟶ COPPER + ZINC SULPHATE (2)

Zinc dissolves in dilute sulphuric acid, displacing hydrogen in just the same way:

$$\text{ZINC} + \text{SULPHURIC ACID} \longrightarrow \text{HYDROGEN} + \text{ZINC SULPHATE} \qquad (3)$$

It is clear that, in this reaction, hydrogen has taken the place of copper in equation (2): in fact, we can write *hydrogen sulphate*† instead of *sulphuric acid*, thus showing its chemical composition more clearly.

$$\text{ZINC} + \underset{\textit{sulphuric acid}}{\text{HYDROGEN SULPHATE}} \longrightarrow \text{HYDROGEN} + \text{ZINC SULPHATE} \qquad (4)$$

Similarly

$$\text{IRON} + \underset{\textit{sulphuric acid}}{\text{HYDROGEN SULPHATE}} \longrightarrow \text{HYDROGEN} + \text{IRON SULPHATE} \qquad (5)$$

and

$$\text{MAGNESIUM} + \underset{\textit{sulphuric acid}}{\text{HYDROGEN SULPHATE}} \longrightarrow \text{HYDROGEN} + \text{MAGNESIUM SULPHATE}^{\dagger} \quad (6)$$

In the same way, another chemical name for *hydrochloric acid* is *hydrogen chloride*,† hence we can write:—

$$\text{ZINC} + \underset{\textit{hydrochloric acid}}{\text{HYDROGEN CHLORIDE}} \longrightarrow \text{HYDROGEN} + \text{ZINC CHLORIDE}^{\dagger} \qquad (7)$$

and

$$\text{IRON} + \underset{\textit{hydrochloric acid}}{\text{HYDROGEN CHLORIDE}} \longrightarrow \text{HYDROGEN} + \text{IRON CHLORIDE}^{\dagger} \qquad (8)$$

and

$$\text{MAGNESIUM} + \underset{\textit{hydrochloric acid}}{\text{HYDROGEN CHLORIDE}} \longrightarrow \text{HYDROGEN} + \text{MAGNESIUM CHLORIDE}^{\dagger} \quad (9)$$

The important thing to notice about all the reactions (3) to (9) is that in every case *the metal displaces the hydrogen of the acid.*

WILL METALS ALSO DISPLACE HYDROGEN FROM WATER?

Just as many metals displace hydrogen from acids, some metals will displace hydrogen from *water*, under suitable conditions.

Thus, the very active metals *potassium* and *sodium* displace hydrogen from cold water, at the same time dissolving in the water. You will remember that potassium and sodium are bright, silvery metals which are so soft that they can be cut with a knife. They oxidize† so rapidly in air that they have to be kept under *kerosene*, (or paraffin oil) a liquid that contains *no oxygen.* As these elements are so very active it will be safer if your teacher demonstrates the next few experiments to you.

WHAT IS THE ACTION OF POTASSIUM ON WATER?

(*Demonstration.*) When a small piece of potassium is dropped into an evaporating dish containing water coloured red with litmus, the reaction is so vigorous that the metal melts and runs about on the surface of the water. (Potassium is 'lighter' than water.) Hydrogen is given off and it catches fire of itself owing to the great heat of the reaction, burning with a pale purple flame because some potassium vapour is mixed with the hydrogen. (Any compound containing potassium colours a flame pale purple.) The litmus turns blue because *potassium hydroxide* (caustic potash†), an alkali, is formed. Hence, *potassium easily displaces hydrogen from cold water*, *or*

$$\text{POTASSIUM} + \underset{\textit{water}}{\text{HYDROGEN OXIDE}} \longrightarrow \underset{\textit{caustic potash}}{\text{POTASSIUM HYDROXIDE}} + \text{HYDROGEN}$$

WHAT IS THE ACTION OF SODIUM ON WATER?

(*Demonstration.*) A *dry* glass tube (about 6 in. by $\frac{1}{2}$ in.) is clamped upright with its lower end dipping about 1 in. under some water in a glass dish, as shown in Fig. 67. The water is coloured red with litmus and a small piece of sodium is dropped into the tube. There is a vigorous reaction (although not quite so vigorous as when potassium is used, since the hydrogen does not catch fire of itself).

The sodium melts and jumps about on the surface of the water. (Sodium is 'lighter' than water). When a light is put to the mouth of the tube, the hydrogen catches fire and burns with a bright yellow flame, because some sodium vapour is mixed with the hydrogen. (Any compound containing sodium colours the flame bright yellow.) The litmus turns blue because *sodium hydroxide* (caustic soda)[†] is formed when sodium reacts with water, and the solution feels slippery, or 'soapy', when rubbed between finger and thumb. Hence, *sodium easily displaces hydrogen from cold water*, *or*

SODIUM + HYDROGEN OXIDE → SODIUM HYDROXIDE + HYDROGEN
water *caustic soda*

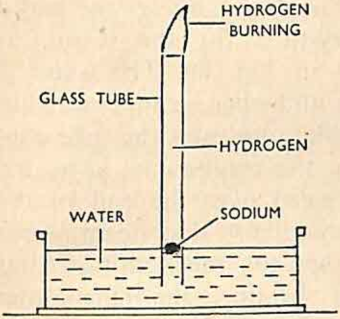

FIG. 67. Action of sodium on water.

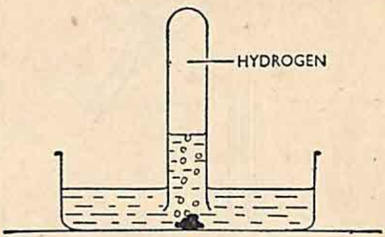

FIG. 68. Action of calcium on water.

WHAT IS THE ACTION OF CALCIUM ON WATER?

The metal calcium does not combine with oxygen so easily as do sodium and potassium, hence its action on water is not so vigorous. As calcium sinks in water we can collect the hydrogen in an inverted test-tube. Invert a test-tube filled with water over a piece of calcium in a dish of water (see Fig. 68). When the test-tube is full of the gas, test it by putting a light to the mouth of the tube. Then filter a little of the water used in this experiment and breathe through the filtrate.

What happens?.................................

Hence the liquid is *lime-water*, made by dissolving calcium in water. (We usually make lime-water by dissolving lime or slaked lime in water.) This experiment shows that *calcium displaces hydrogen from water fairly easily.*

CALCIUM + HYDROGEN OXIDE → CALCIUM HYDROXIDE + HYDROGEN
water *slaked lime*

The only common elements that displace hydrogen from cold water are *potassium*, *sodium*, and *calcium*, but some other metals, e.g. magnesium and iron, although they will not displace hydrogen from cold water, will do so from *steam*.

WHAT IS THE ACTION OF HEATED MAGNESIUM ON STEAM?

(*Demonstration.*) A flask is half-filled with water and fitted with a cork carrying a *safety-tube* and a delivery-tube for the steam, as shown in Fig. 69. The water is boiled, and when steam comes out of the delivery-tube, the tube containing the magnesium is heated and placed over the end of the delivery-tube so that steam passes over the hot magnesium. After further heating, the magnesium catches fire and burns brightly in the steam, just as it burnt in air in our early experiments (see p. 14). The magnesium combines with the oxygen of the steam (hydrogen oxide) forming *magnesium oxide*. At the same time, hydrogen is displaced from the steam and burns at the end of the tube. Hence, *heated magnesium displaces hydrogen from steam*, or

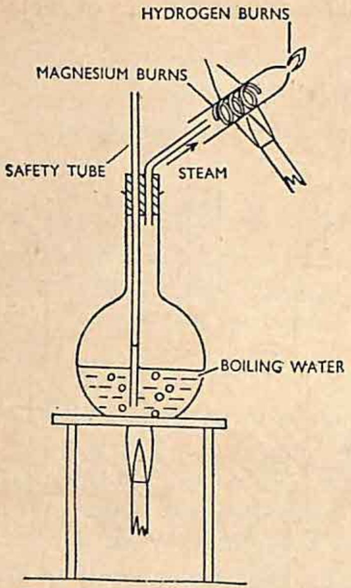

FIG. 69. Burning magnesium in steam.

MAGNESIUM + HYDROGEN OXIDE → MAGNESIUM OXIDE + HYDROGEN
steam

WHAT IS THE ACTION OF HOT IRON ON STEAM?

(*Demonstration.*) The apparatus shown in Fig. 70 is used for passing steam over iron powder in a 'hard' glass tube which is strongly heated. The oxygen of the steam combines with the iron, forming *iron oxide*, and hydrogen is displaced, collecting in the gas-jar. (This is not the same oxide that is present in iron rust, but it has the same composition as the magnetic iron oxide formed when iron is burnt in oxygen.)

Hence, *hot iron displaces hydrogen from steam*, or

$$\text{IRON} + \underset{\textit{steam}}{\text{HYDROGEN OXIDE}} \longrightarrow \text{IRON OXIDE} + \text{HYDROGEN}$$

The last five experiments show that we have a series of metals that displace hydrogen less and less easily from potassium down to iron, in the following order:—(1) *potassium*, (2) *sodium*, (3) *calcium*, (4) *magnesium*, (5) *iron*. In other words, *potassium is more active chemically than sodium, while sodium is more active than calcium, and so on, down to iron, which is the least active of these five elements*. Copper, silver, and gold are still less active: they *never* displace hydrogen from water or acids.

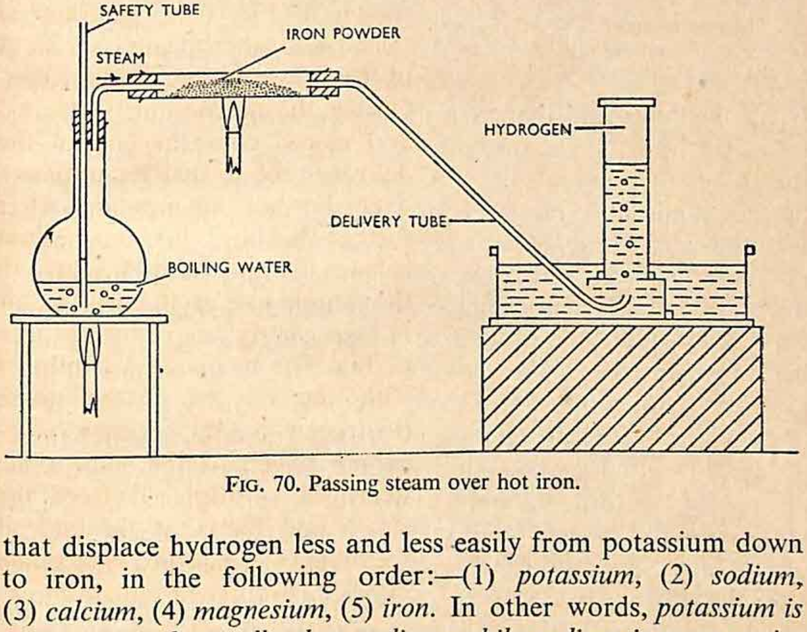

FIG. 70. Passing steam over hot iron.

Learning Exercises on Chapter V will be found on pp. 7–9 of *General Science Workbook I*.

Note.—Before reading this chapter, the student should read Appendix D to learn what is meant by the term 'scientific accuracy'.

CHAPTER VI

MEASUREMENT

> *When you can measure what you are speaking about and express it in numbers, you know something about it, and when you cannot measure it, when you cannot express it in numbers, your knowledge is of an insufficient and unsatisfactory kind.—Lord Kelvin* (1824–1907).

It is sometimes said that '*Science is measurement*', and there is a lot of truth in this because most of our present knowledge about the things of everyday life is the result of careful measurement. Science made little progress for about 2,000 years because early scientific ideas were based only on what men *thought* of things, i.e. mere *opinions*, and it was not until careful measurement was introduced that scientific ideas could be based on *facts*. In our earliest lessons on air, we had to measure *weight* and *volume* before we could explain *what air is*. In later lessons you will find that, until you can *measure* them, you will know very little about pressure, heat, force, mechanical work, electricity, chemical change, food values, and so on. All scientific measurement is based on measuring the three different kinds of *quantities—length*, *weight*, and *time*—and all our other measurements can be stated in *units* of length, weight, and time.

In the introduction to this science course we saw that we have to find the answers to such questions as 'What is it?', 'What does it do?', and 'How does it do this?' To these questions we must now add another, 'How *much* is it?'

HISTORICAL UNITS OF LENGTH

The measurement of *length* (and if you can measure lengths you can also measure *areas* and *volumes*) has always been a matter of great everyday importance, and from the earliest times, every nation of any civilization has used some *units* or other. The oldest units of length were taken from parts of the human body. For example, in the Old Testament we read about *cubits*.† This cubit, used by the Egyptians, the Jews, and the Greeks, was the distance from the point of the elbow* to the tip of the middle finger, i.e. about 18 inches. A *span*† was the distance from the tip of the thumb to the tip of the little finger with the fingers stretched out to their fullest extent, i.e. about 9 inches (or half a cubit). A *palm*† was the width of the palm* of the hand, i.e. about 3 inches (one-third of a span, or one-sixth of a cubit). A *digit*† was the width of a finger, about $\frac{3}{4}$ in. (one-quarter of a palm, or one-twenty-fourth of a cubit). Nearly every nation has used a unit that corresponds* to our present-day *foot*, and this came from the length of a man's foot. The English *yard* is said to have been the length of the arm of the English King Henry the First.

Some British units of length came from agriculture* in Anglo-Saxon times. The *pole*,† or *rod* (16 ft. 6 in., or $5\frac{1}{2}$ yards) was four times the length of the pointed stick carried by the farmer when ploughing with oxen (and used to prick,* or goad,* the oxen when they went too slowly). When the farmer wanted to measure the length of a piece of ground, he would naturally use this pointed stick, and since all farmers used ox-goads of nearly the same length, they supplied a convenient unit of length. A *furlong*† is a shortened form of 'a furrow* long', this being the length of furrow that oxen could plough without stopping for a rest: and this length, agreed upon as forty poles, could be measured off by the farmer with his ox-goad. An *acre* was the area that a team* of oxen could plough in one working day.

In olden times, therefore, each nation had its own system of measurement just as it had its own language, both being equally difficult for foreigners to understand. As trade extended, it became necessary to have *uniform standards* of weights and measures to do away with this confusion in buying and selling. Uniform standards also stop cheating. For example, if cloth was sold by the cubit, measured off by a man's arm, dishonest shopkeepers would employ only small men with short arms for selling cloth.

Two systems of measurement are used in English-speaking countries, (*a*) *the British Imperial System*,† and (*b*) *the Metric System*.†

THE BRITISH SYSTEM

The British Unit of Length, the *Imperial Standard Yard*, was defined* by law in 1878 as *the distance* (at 62° F.) *between two marks on a certain bar of metal kept in London*. All our yard measures are copies of this length, and all other British units of length are now got from the Standard Yard: thus, a foot is one-third of a yard; an inch is one-twelfth of a foot or one-thirty-sixth of a yard, and so on. The *Imperial Standard Pound* is the weight of a platinum cylinder kept in London, and the *Imperial Standard Gallon* is the volume occupied by 10 pounds of pure water at 62° F.

British measures have two disadvantages:—(*a*) They are difficult to calculate with; thus, if you want to change miles to yards, or yards to poles, you have to multiply or divide by awkward numbers (e.g. there are 272¼ sq. ft. in a sq. pole). (*b*) There is no simple relation between the units of length, volume, and weight, i.e. between the *yard*, the *gallon*, and the *pound* (e.g. there are 277·274 cubic inches in a gallon). A system of weights and measures which avoids these difficulties is that based on the *metre*,† namely, the *Metric System*.

THE METRIC SYSTEM

At the time of the French Revolution (which began in 1789) the inconvenience and confusion caused by the older systems of measurement caused the new Republican Government to appoint a committee of scientific men (Lavoisier being one of them) to work out a better and simpler system. This committee produced the *Metric System*, which is now used all over the world for scientific purposes, and in many countries for everyday purposes as well.

The metric unit of length is the *International Prototype* Metre. This is the distance* (at 0° C.) *between two marks on a certain bar of metal kept in France.* (This distance is equivalent* to 39·37 inches.[1]) For most laboratory purposes we measure lengths in centimetres† (hundredths of a metre) or in millimetres† (thousandths of a metre).

The metric unit of *volume* is the *litre.*† This is the volume of *one cubic decimetre,*† i.e. the volume of a cube* whose sides are one-tenth of a metre long. Hence, for practical purposes in this science course, 1 *litre* = 1,000 *cubic centimetres.*

The metric unit of *weight* is the kilogram,† and this is the weight of a certain lump of metal kept in France, which has the same weight as *one litre of pure air-free water at* 4° C. (see also p. 146). For practical purposes in this science course, *the gram*† *is the weight of one cubic centimetre of water.*

BRITISH SYSTEM	METRIC SYSTEM
12 inches (in.) = 1 foot	10 millimetres (mm.) = 1 centimetre
3 feet (ft.) = 1 yard	10 centimetres (cm.) = 1 decimetre
5½ yards (yd.) = 1 pole	10 decimetres (dm.) = 1 metre
40 poles = 1 furlong	10 metres (m.) = 1 dekametre
8 furlongs = 1 mile	10 dekametres (Dm.)† = 1 hectometre
	10 hectometres (Hm.)† = 1 kilometre†

Useful Equivalents.—1 yard = 0·9 metre. 1 mile = 1·6 kilometres (km.). 1 kilometre = 5 furlongs. 1 kilogram = 2·2 lb.

Not all of these metric units are in common use and we shall only use the following in this science course:—metre (m.), kilometre (km.), centimetre (cm.), millimetre (mm.), litre (l.), cubic centimetre (c.cm.), gram (gm.), kilogram (Kg.).

---

[1] The metre was originally intended to be one ten-millionth part of the distance between the Equator* and the North Pole.

The Metric System has the following advantages:—(*a*) *It is a decimal* system.* This makes the metric tables very simple indeed since they have only one number—10—to multiply or divide by. Because of the awkward numbers involved* it takes many hours to learn the tables for the British system of weights and measures. In the metric tables the figures remain the same *and it is only necessary to move the decimal point* in changing from one unit to another; (*b*) *there is a simple relation between the units of length, volume, and weight*, e.g. a litre is a cubic decimetre, and a kilogram is the weight of a litre of water.

(N.B. You may find that some of your laboratory apparatus is graduated in *millilitres*† (ml.) but for any volume measurements you make in this science course you can regard millilitres as equivalents of cubic centimetres.)

THE MEASUREMENT OF LENGTH

HOW TO MEASURE ACCURATELY THE LENGTH OF STRAIGHT LINES

1. Examine your ruler, and notice that one edge is divided into inches and tenths of an inch, while the other edge is divided into centimetres and tenths of a centimetre (millimetres). (N.B.—In the following exercises on measurement, use *decimals* and not fractions, giving your results to *three significant* figures* only.) Draw three straight lines on paper, AB = 3·00 in., CD = 4·00 in., and EF = 5·00 in. long. Measure these lines in centimetres and tenths of a centimetre, taking the following precautions*:—(*a*) Unless the ruler has a very thin edge, place it on its side as shown in Fig. 71, i.e. with the marks on the ruler as near as possible

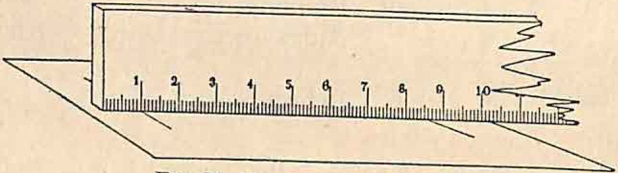

FIG. 71. How to use a ruler.

to the point from which you are measuring. (*b*) If the marks begin at the very end of the ruler, do not use the end marks, but measure 'by difference' as shown in Fig. 71. (*c*) Keep your eye vertically* over the point you are measuring to. From your results, calculate the number of centimetres in one inch.

(i) AB = 3·00 in. = ...cm., therefore, 1 in. = ...cm.
(ii) CD = 4·00 in. = ...cm., therefore, 1 in. = ...cm.
(iii) EF = 5·00 in. = ...cm., therefore, 1 in. = ...cm.

Since the *average* of several results is nearer the truth than one single measurement take the average of these three results.

12·00 in. = ...cm.
Therefore, 1 inch = ...centimetres.

Draw a *graph* that will enable you to turn inches into centimetres without calculation.

HOW TO MEASURE THE LENGTHS OF CURVED LINES

2. Draw a circle of 2·00 in. radius* on a sheet of paper. Tie a small knot near the end of a piece of cotton thread and, marking the circle where you start, lay the knot on the mark and measure the length of the circumference* of the circle, laying the thread along the line a little at a time and holding it down with the forefinger of each hand. When you come to the starting-point, pinch the thread at this point and lay it straight along your ruler, reading off the length in centimetres.

Do this three times and find the average.

Circumference of circle = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average result is.........÷ 3 = ...cm.

---

3. A better way of measuring the length of a curved line is to use a *map-measurer*. This has a small rough-edged wheel mounted* on an axle* which is a fine screw (see Fig. 72). The wheel is first screwed along to the end of the axle near the pointer, and the mark on the wheel is set opposite the pointer. To measure the length of a curved line, the map-measurer is held upright with the pointer over

the end of the line to be measured, and it is then wheeled along the line to its other end. The map-measurer is then wheeled backwards along a ruler until the mark on the wheel reaches the pointer again, and the distance travelled along the ruler is the length of the line. Measure, in centimetres, the circumference of your 2-in. circle by this method. Do this three times and find the average.

Circumference of circle = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average result is .... ÷ 3 = ... cm.

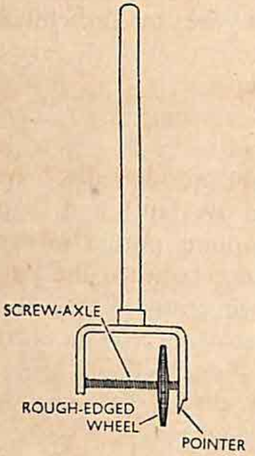

FIG. 72. A map measurer.

4. From a map of your district, find how far you actually travel to school. Measure the distance on the map, (i) using a map-measurer, and (ii) using a piece of thread.

(i) Distance on map (using a map-measurer) = ... in.
But .... inch on the map = ... miles on the ground.
Therefore, the distance travelled to school is.............miles.

(ii) Distance on map (using a piece of thread) = ... in.
But .... inch on the map = ... miles on the ground.
Therefore, the distance travelled to school is .... miles.

Which do you think is the more accurate result, (i) or (ii)?......
Why?..

How far is it from your house to the school *in a straight line cross-country?* ....

5. Measure the circumference of the given cylinder by wrapping a piece of thread round it ten times. Unroll the thread and measure the length of ten complete turns. Do this three times and find the average.

Ten times the circumference = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, average result for ten times the circumference = ... ÷ 3 = ... cm.

Therefore, the circumference of the cylinder is

.... ÷ 10 = ... cm.

6. Measure the circumference of the given wooden disc* by wrapping a strip of paper round it so as to overlap,* and then pricking a hole with a pin through the overlapping part. Unwrap the paper, lay it flat, and measure the distance between the two holes. Do this three times and find the average.

Circumference = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average circumference of the disc is

.... ÷ 3 = ...cm.

7. Take a large coin or metal washer* and put a tiny spot of ink on its edge. Roll it along a piece of paper so that it leaves at least two marks on the paper. Measure the distance between two marks. Do this three times and find the average.

Circumference = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average circumference is

.... ÷ 3 = ...cm.

HOW TO MEASURE THE DIAMETER OF A CYLINDER

8. Arrange two set-squares,* a ruler, and the given cylinder as shown in Fig. 73. Measure the diameter* three times, turning the cylinder and using a different part of the ruler each time. Find the average of your three measurements.

Diameter of cylinder = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average diameter is

.... ÷ 3 = ...cm.

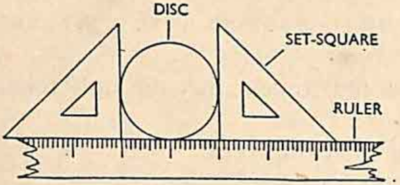

FIG. 73. Measuring the diameter of a cylinder.

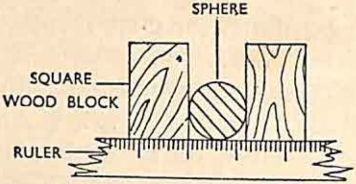

FIG. 74. Measuring the diameter of a sphere.

HOW TO MEASURE THE DIAMETER OF A SPHERE

9. Arrange two square wooden blocks, a ruler, and the given sphere* (e.g. a large ball-bearing*) as shown in Fig. 74. Measure the diameter of the sphere three times, using a different part of the ruler each time, and turning the sphere between each measurement.

Diameter of sphere = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average diameter of the sphere is

.... ÷ 3 = ...cm.

HOW TO USE THE OUTSIDE CALIPERS

10. Use the *outside calipers*† (see Fig. 75) to measure the diameter of the given sphere, opening the calipers so that the widest part of the sphere will just slip between the jaws AB without being scratched. Then measure the distance between the points of the calipers with a ruler. Make three measurements of the diameter, turning the sphere between each measurement.

Diameter of sphere = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average diameter of the sphere is

.... ÷ 3 = ...cm.

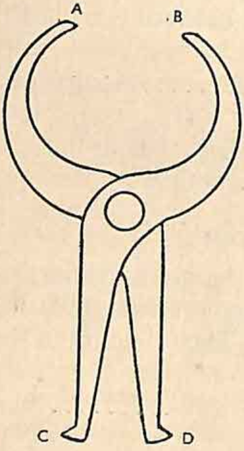

FIG. 75. Combined outside and inside calipers.

11. Use the *inside calipers* (see Fig. 75) to measure the inside diameter of the given metal tube. Make three measurements of the tube in different positions and find the average diameter CD.

Inside diameter = (i) .... cm. (ii) .... cm. (iii) .... cm.

Therefore, the average inside diameter is

.... ÷ 3 = ... cm.

HOW THE VERNIER WORKS

The *vernier*† (invented in 1631) is a very useful device* for measuring fractions of scale divisions accurately, e.g. to 0·01 in. or to 0·01 cm. It consists of a short *vernier scale* sliding alongside the *main scale*, and marked so that 10 *vernier divisions* = 9 *scale divisions*, e.g. on a centimetre vernier, 10 vernier divisions = 9 mm., or 1 vernier division = 0·9 mm. In the upper diagram of Fig. 76, the distance between the first mark on the fixed scale and the first mark on the vernier scale is 0·1 mm. Similarly, the distance between the second mark on the fixed scale and the second mark on the vernier scale is 0·2 mm., and so on, until the distance between the ninth scale division and the ninth vernier division is 0·9 mm.

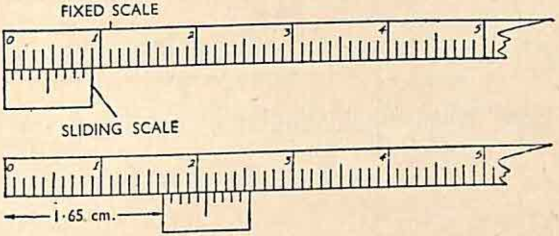

FIG. 76. Principle of the Vernier.

The lower diagram of Fig. 76 shows how a vernier works. The reading is 1·6 cm. *plus* a fraction of a millimetre*. Looking along the vernier, we see that the fifth division of the vernier is exactly opposite a division on the fixed scale. Looking to the left of this, the fourth vernier mark is 0·1 mm. to the right of the next fixed scale mark. Similarly, the third vernier mark is 0·2 mm. to the right of the next mark on the fixed scale, and so on, until we reach the zero mark on the vernier, which is 0·5 mm. to the right of the 1·6 cm. mark on the fixed scale, i.e. *the reading is* 1·65 *cm.*

When using a decimal vernier, therefore, *look along the vernier until you find a vernier mark that is exactly opposite a mark on the fixed scale: the number of this vernier mark gives the required decimal.*

HOW TO USE THE VERNIER SLIDING CALIPERS

Before using the instrument shown in Fig. 77, the first thing to do is to close its *jaws* AB and see whether the zero mark on the sliding scale is exactly opposite the zero mark on the fixed scale. If these two marks are not exactly opposite each other, then there is a *zero error* which must be noted. If the zero mark on the sliding scale is to the *right* of the zero mark on the fixed scale, then the zero error must be *subtracted** from *your measurements.*

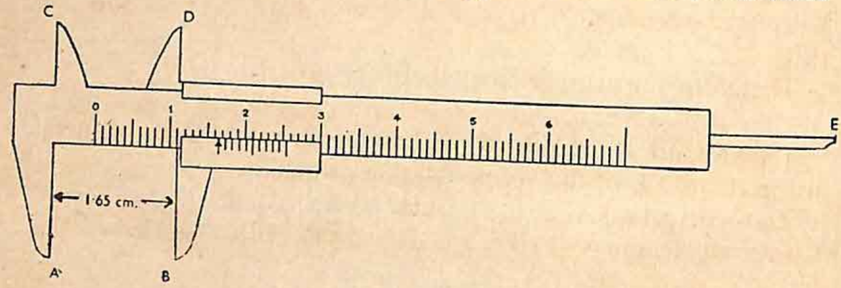

FIG. 77. Vernier sliding calipers.

If the zero mark on the sliding scale is to the *left* of the zero mark on the fixed scale, then the zero error must be *added* to your readings. *Measuring instruments must always be corrected for zero error.*

12. Use the vernier sliding calipers to measure the thickness of fifty pages of this textbook. Then use this measurement to find the average thickness of one sheet.

Zero correction = ... cm. (State whether + or −.)
Scale reading = ...cm.
Therefore, the corrected reading = ... cm.

But this is the thickness of fifty sheets, hence the average thickness of each single sheet is .... ÷ 50 = ... cm.

13. Measure the outside diameter of the given steel washer, using the *jaws* AB of the vernier sliding calipers.

Zero correction = ... cm.
Corrected readings = (i) ......cm. (ii)...... cm. (iii) ......cm.
Therefore, the average outside diameter is
.... ÷ 3 = ... cm.

14. Measure the inside diameter of the hole in the given washer, using the *ears* CD of the vernier sliding calipers.

Zero correction = ... cm.
Corrected readings = (i) .... cm. (ii) .... cm. (iii) .... cm.
Therefore, the average diameter of the hole is
.... ÷ 3 = ... cm.

15. Measure the depth of the hole in the given piece of metal, using the *tail* E of the vernier sliding calipers.

Zero correction = ... cm.
Corrected readings = (i) .... cm. (ii) .... cm. (iii) .... cm.
Therefore, the average depth of the hole is
.... ÷ 3 = ... cm.

HOW A MICROMETER SCREW-GAUGE WORKS

The *screw-gauge*† (invented in 1638) is an instrument for measuring small lengths with great accuracy, e.g. to 0·001 in. or 0·01 mm. When the *screw-head* is given one complete turn, the tip of the screw moves forward by the distance between two *threads** of the screw. This distance is called the *pitch*† of the screw, and it is usually 1 mm. in a metric screw-gauge. There are two scales on a screw-gauge, a *fixed scale* on the body of the instrument and a *revolving* scale* on the screw-head (see Fig. 78). On a metric screw-gauge, the fixed scale is divided into millimetres, and the revolving scale is divided into 100 equal parts, so that each of these divisions represents one-hundredth of a complete turn, i.e. 0·01 mm. at the tip of the screw.

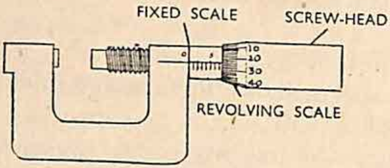

FIG. 78. Micrometer screw-gauge.

16. Examine a micrometer* screw-gauge, and show your teacher the instrument set to read 1·23 mm. (N.B.—*The screw-head must be turned lightly with the finger and thumb—no force should be used.*)

HOW TO MEASURE THE DIAMETER OF A SMALL SPHERE

17. First find the zero error of your instrument by reading it when the jaws are closed and remember to add or subtract any zero error from your readings. Then use the micrometer screw-gauge to measure the diameter of a small steel ball, in millimetres. Take the average of at least three readings, turning the ball between each measurement.

Zero correction = ... mm.

Corrected readings = (i) .... mm. (ii) .... mm. (iii) .... mm.

Therefore, the average diameter is

.... ÷ 3 = ... mm.

HOW TO MEASURE THE DIAMETER OF A WIRE

18. Use the micrometer screw-gauge to measure the diameter of the given piece of wire, in millimetres. If an inch screw-gauge is available, also measure the diameter of the same wire in inches

(a) Zero correction = ... mm.

Corrected readings = (i)............mm. (ii) .... mm. (iii) .... mm.

Therefore, the average diameter is .... mm.

(b) Zero correction = ... in.

Corrected readings = (i) .... in. (ii) .... in. (iii) .... in.

Therefore, the average diameter is .... in.

THE MEASUREMENT OF AREA

In mathematics lessons you will have learnt how to find the area of *regular figures* like rectangles,† parallelograms,† triangles and circles, where it is easy to work out simple rules and formulas for calculating their area. In everyday life, however, it is often necessary to find the area of an *irregular figure*, and this can be done by using squared paper, as follows.

HOW TO FIND THE AREA OF AN IRREGULAR FIGURE

19. Fig. 79 shows the outline map of an island drawn to the scale of 1 in. = 4 miles (i.e. $\frac{1}{4}$ in. = 1 mile). The easiest way to find the area of this island, to the nearest square mile, is to lay a sheet of tracing-paper, ruled into $\frac{1}{4}$-in. squares, over the map, and trace the coast-line of the island on the squared tracing-paper (as shown in Fig. 79). Now count the number of *complete* $\frac{1}{4}$-in. squares in rows 1 to 9 and write down the total .... There is a simple method for getting a fair *average* value for the remaining *parts of squares*:—Where the coast-line cuts a square, *if more than half the square is inside the outline, count it as one whole square; if less than half a square is inside, do not count it at all* (i.e. ignore* the squares marked with a cross in Fig. 79). Add together your two totals (....... + ... = ...) Since each $\frac{1}{4}$-in. square represents one square mile, your final total is very close to the actual area of the island in square miles.

20. In the same way, find the area of the country in which you live, from a map, in square miles, using a sheet of tracing-paper ruled in 1-in. and 0·1 in. squares.

Area of .... on map = ... sq. in.

But 1 in. on the map = ... miles on the ground, therefore 1 sq. in. on the map = ... square miles on the ground.

Therefore, area of .... is .... × .... = ... square miles.

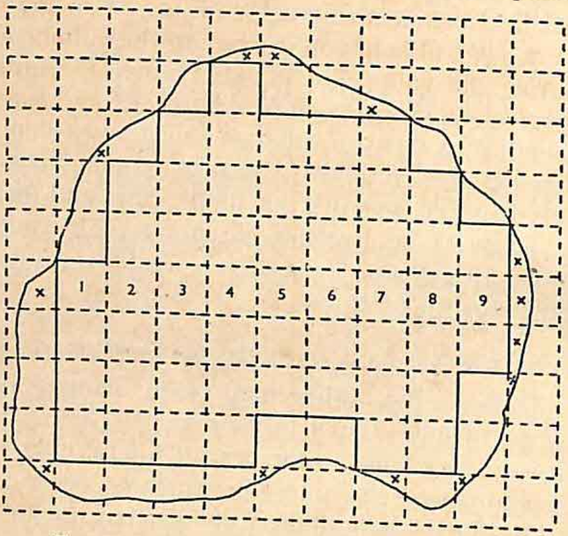

FIG. 79. Finding the area of an irregular figure.

THE MEASUREMENT OF VOLUME

The volume of anything is the amount of space it occupies, and in mathematics lessons you will have learnt how to calculate the volume of *regular solids*, e.g. prisms,† pyramids,† and spheres. In everyday life, however, such regular, perfectly geometrical solids are rarely met with, and in this science course we shall be more concerned with finding the volume of *irregular solids*, of *liquids*, and of *gases*. In such cases, the rules and formulas for finding the volume of regular solids are of little help.

HOW TO MEASURE THE VOLUME OF LIQUIDS

A liquid has a definite volume but it has no definite shape, hence its volume can be found by pouring it into a graduated* measuring vessel. The surface of a liquid in a narrow vessel, however, is not flat, but curved, and *when measuring the volume of a liquid in any graduated vessel, you must always read from the surface at the centre of the vessel, with your eye at the same horizontal level.* A piece of white paper held behind the vessel, and just below the surface, as shown in Fig. 80, will help you to read off the volume accurately. For measuring the volume of liquids in the laboratory we use *measuring cylinders*, *measuring flasks*, *pipettes*,† and *burettes*.†

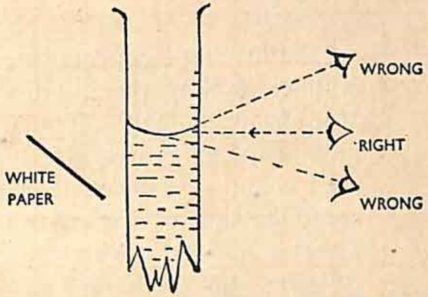

FIG. 80. How to read the level of a liquid.

HOW THE GRADUATED CYLINDER WORKS

The *graduated cylinder* (or *measuring-jar*)* is used for rough measurements of the volume of liquids (see Fig. 81). It is used for *holding* or for *delivering* a measured volume of liquid. Various sizes are used in the laboratory, the commonest being 5 c.cm., 10 c.cm., 25 c.cm., 50 c.cm., 100 c.cm., 250 c.cm., 500 c.cm., and 1 litre.

Examine a graduated cylinder, making sure that you understand what the various graduations represent. The smallest division on a 100-c.cm. cylinder is usually 1 c.cm., and it is possible to estimate* to one-fifth of this, i.e. to 0·2 c.cm. On most cylinders, one set of marks begins at the bottom and these show the volume of liquid *contained* in the cylinder. Some cylinders have another set of marks beginning at the top and reading downwards, and these marks show the volume of liquid *delivered* from the cylinder after

first filling to the top mark. The position of the white paper behind the curved surface and the proper position of the eye are shown in Fig. 80. Always use the smallest (and narrowest) cylinder that will hold the liquid to be measured. Why?............................
....

21. Show your teacher a 50-c.cm. graduated cylinder with 25·0 c.cm. of water in it.

HOW TO FIND THE VOLUME OF AN IRREGULAR SOLID

22. Put 30·0 c.cm. of water in a 50-c.cm. cylinder, adding the last few c.cm. drop by drop from the tap. Slope the cylinder and slide in the given irregular solid (e.g. a cross-head clamp or a piece of chain) so as not to break the glass or lose any water by splashing. The rise of water in the cylinder measures the volume of the solid.

Volume of water *before* adding solid = ... c.cm.

Volume of water *after* adding solid = ... c.cm.

Therefore, *the volume of the solid* = ... c.cm.

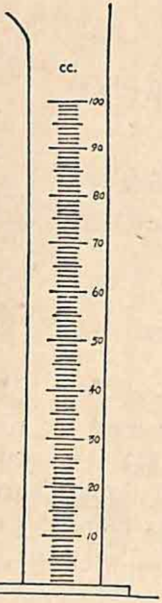

FIG. 81. Graduated measuring cylinder.

HOW THE BURETTE WORKS

The *burette* is a long, narrow, graduated cylinder with either a glass tap or a rubber-tube and spring clip at the bottom, designed to *deliver* volumes of liquids more accurately than a graduated cylinder (see Fig. 82). We generally use 50-c.cm. burettes in the laboratory, graduated from the top downwards in tenths of a cubic centimetre (0·1 c.cm.), so that it is possible to estimate to one-tenth of a division (0·01 c.cm.). Examine a burette. Fill it with water through a small funnel and adjust* the water-level to

0·00 c.cm., *after making sure that the jet below the tap is full of water.*

23. Show your teacher the burette adjusted to read 0·00 c.cm.

HOW TO FIND THE VOLUME OF ONE DROP OF WATER FROM A BURETTE

24. Let fifty drops fall slowly into a test-tube. Then read the new water-level.

Volume of 50 drops = ... c.cm., therefore, the average volume of one drop = ... c.cm.

HOW TO FIND THE VOLUME OF A SMALL LEAD SHOT

25. Adjust the water-level in your burette to 20·00 c.cm. Then count out fifty small lead shot* and drop them into the burette.

Reading of burette *before* adding lead shot = ... c.cm.

Reading of burette *after* adding lead shot = ... c.cm.

Therefore, the volume of 50 lead shot = ...c.cm.

Therefore, the average volume of one lead shot = ...c.cm.

HOW THE PIPETTE WORKS

The *pipette* (see Fig. 83) is designed* to *deliver* one fixed volume of liquid very accurately. Examine a pipette. Put the jet under some water in a beaker and suck air out of the pipette until the water rises above the mark on the tube. Then slip your dry *fore-finger* quickly over the top

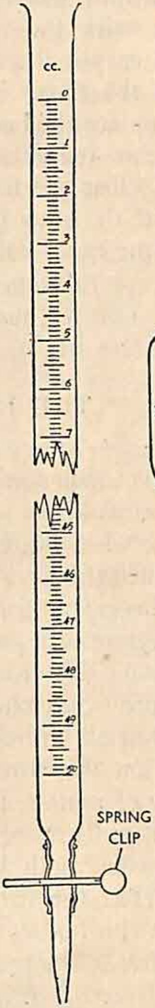

FIG. 82.
Burette.

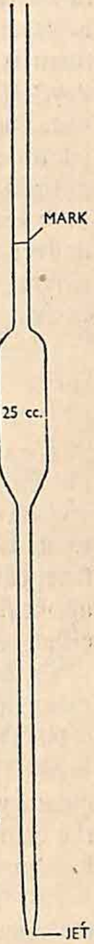

FIG. 83.
Pipette.

end as you remove your mouth. By carefully moving the finger, or by turning the pipette, allow water to escape until the surface is level with the mark on the tube. (Control of this movement is easy if the finger-tip and the top of the pipette are both dry.) If the finger is now removed, most of the liquid will run out. Displace the last drop as follows: hold the pipette so that the jet touches the side of the vessel into which the liquid is being poured, close the top of the pipette with a finger, and warm the bulb with the other hand for a second or two. The pipette will then deliver the exact volume marked in it. In using a pipette, *be very careful not to damage the jet* or you will make the instrument useless. You will use a pipette again shortly.

THE MEASUREMENT OF WEIGHT

The weight of a body[1] *is the force* (*or pull*) *with which the body and the Earth attract each other*. To understand what this means you will have to know something about this *force of attraction* which exists between the Earth and bodies on or above the Earth's surface, called the *force of gravity*. In later lessons you will learn more about *forces*, but for the present you can think of a force as being either a *push* or a *pull*. The force of gravity is a *pull*.

Sir Isaac Newton (1642–1727), after many experiments and observations, concluded:

(i) That all bodies attract each other.

(ii) That this force of attraction depends upon the *mass*,† or *quantity of matter*, in the bodies (i.e. a more 'massive' body, like the Sun, pulls more strongly on a neighbouring body than does a less 'massive' body like the Earth or the Moon).

(iii) That the force of attraction depends upon the distance between the bodies (i.e. the nearer that two bodies are together the greater is the pull between them).

This force of attraction between all bodies is called the force of

---

[1] In *physics*, the term *body* means any portion of matter, i.e. any material object possessing weight. It does not refer only to a living body.

gravitation.† When one of the attracting bodies is the Earth, we speak of the force of *gravity*. The largest *body* that concerns us in our daily life is the Earth, and the quantity of matter in the Earth is very great indeed. Hence, although the pull between two blocks of iron hanging side by side, a few inches apart, is so small that we never notice it in everyday life, the Earth is so big that we always notice its pull on other objects. This pull of the Earth on a neighbouring body is called *the weight of the body*, and it is expressed as *grams-weight* (*gm. wt.*), *pounds-weight* (*lb. wt.*), etc.

If a block of iron is held on the hand, we feel it pressing downwards and we say that it is heavy, i.e. it has weight. If the hand is taken away, the block of iron, still attracted by the Earth, falls to the ground. If we hang the block from a spring, the extension of the spring measures the pull of the Earth, i.e. the *weight* of the iron. Hence a *spring balance* provides an easy way of measuring weight.

The pull between two bodies is greatest when they are closest together, hence a block of iron taken far above the Earth's surface in a balloon will weigh less than at sea-level, since it will be farther from the centre of the Earth. If we travelled about the Earth's surface with a block of iron hanging from a spring balance we should find that the extension of the spring was not always exactly the same, e.g. it would be greater at the Poles (where the Earth's diameter is less) than on the Equator (where the Earth's diameter is greater). This difference in weight is never more than about 0·5 per cent., hence a spring balance is accurate enough for most of our elementary* work.

MASS AND WEIGHT

We have seen that the *weight* of a body is the force with which the body and the Earth attract each other. In the Metric System this force is expressed in *grams-weight* (*gm. wt.*). It was pointed out, in the last paragraph, that the weight of a block of iron varies slightly as it is carried about the Earth's surface, and in fixing a standard *unit of weight* it is therefore necessary to refer to some particular part of the Earth. Scientists have agreed that *one gram-weight* is to be defined as the force acting on a *mass of one gram* at sea-level in latitude 45°. But what do we mean by the *mass* of a body? So far we have been concerned only with the effects of *gravitational forces* on bodies. We know from our own experience that it needs a greater force to roll an iron ball *horizontally* along the ground than it does to roll a ball of the same size made of rubber. The property of matter involved here is known as its *mass*. Mass is sometimes described as '*the quantity of matter in a body*', but this definition does not make us much wiser. It is easier to understand the meaning of *mass* if we think of *mass* as a *measure of the resistance offered by matter to changes in its motion*. An iron ball is more massive (i.e. it has a greater mass) than a rubber ball of the same diameter because it moves less easily than the rubber ball when pushed with the same force.

The metric unit of mass is the gram, and this is one thousandth part of the mass of a lump of non-rusting metal, kept in safety at Sèvres, near Paris. This lump of metal is called the *International Prototype Kilogram*† and, in 1889, 46 copies were made and distributed to different scientific centres throughout the world.

The men who decided on this unit of mass intended the International Prototype Kilogram to have a mass equal to that of a litre of air-free water at 4° C., but more accurate measurements have shown that the original lump of metal was made slightly too large. It is, however, useful to remember that the mass of 1 c.cm. of water at 4° C. is very nearly equal to 1 gm.

In order to compare the masses of two bodies we have to observe the effects of the same force upon both bodies. The most convenient force to use is that of *gravity*; in other words, *we compare masses by measuring weights*. Unfortunately for this purpose, the force of gravity is not the same at every part of the Earth's surface. As a body of mass 1 gm. is moved from the Pole to the Equator, its mass remains unchanged, but its *weight* decreases slightly. You will remember that a mass of one gram has a weight of one *gram-weight* only at sea-level in latitude 45°. But the variation of the gravitational force over the Earth's surface is very small, and in the experiments in this course you may take it that a body of *mass* M *grams* has a *weight of M grams-weight*.

In very accurate scientific measurements of mass we should have to allow for the variation of weight in different latitudes. We overcome this difficulty by using a *balance*, of the type shown in Fig. 102, instead of a *spring balance*. We measure weights by balancing them against equal standard weights. For instance, if we use a scientific balance (which is an accurate pair of scales) to weigh a block of iron with brass weights at sea-level and then weigh it again up a mountain, we shall find that the same brass weights exactly balance the iron at each place because, although the iron weighs less up the mountain (owing to its greater distance from the centre of the Earth), so do the brass weights, and in exactly the same proportion. Hence, for all accurate work in science, we use a balance (or pair of scales), and *compare* the weight of an object with that of our brass 'weights'. In this science course, however, we shall often use spring balances, which are accurate enough for most of our work and also much quicker to use.

See Appendix C (pp. 176–181) for a description of a scientific balance and how to use it.

DENSITY

THE RELATION BETWEEN MASS AND VOLUME

Compare a 1-lb. block of wood with a 1-lb. block of iron or brass. First make sure that their *weight* is the same by putting them on a balance or a pair of scales. Notice the big difference in their size or *volume*, as shown in Fig. 84. Hold the block of wood in one hand and the block of metal in the other.

Do they both *feel* equally heavy? . .

. . . .

Although they are both of the *same weight*, the metal 'feels heavier' than the wood.

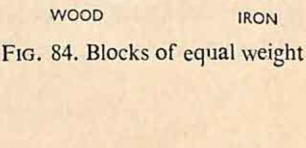

FIG. 84. Blocks of equal weight

Compare the weight of a cube of wood with that of a cube of metal *of the same size*. You can weigh them either on a spring balance or on a scientific balance, but if one is of M grams-weight, you may take its mass to be M grams. Notice that although they have the same volume, their weights, and therefore their masses, are very different. Your experiment could be repeated with similar cubes of many different substances, and you would find that they could be arranged in order, from the heaviest down to the lightest, e.g. platinum, gold, lead, silver, copper, iron, zinc, aluminium, granite, chalk, hardwood, softwood.

When we say, then, that iron is 'heavier' than aluminium, we mean that a block of iron weighs more than an aluminium block of the same size (or volume). But we also use the word 'heavier' in another way, as when we say that one block of iron is heavier than another. As it is confusing to use the same word in two different ways, we shall now use the word *density* when we mean *mass in relation to volume*. Thus platinum is *denser* than any of the substances named in the list above; hardwood is *denser* than softwood.

The *density of a substance is the mass of unit volume of it*. On the Metric System, the density of a substance is the mass of one cubic centimetre of it. On the British system, density is measured in pounds per cubic foot.

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}$$

For example, the density of water is 1 gram per cubic centimetre, and the density of mercury is 13·6 gm. per c.cm. The density of a substance is one of its most characteristic properties, hence the accurate measurement of density is of great everyday importance in every branch of science and engineering. We shall now find the density of some common materials.

26. Find the density of brass, copper, zinc, aluminium, and wood by weighing 1 cm. cubes of these materials.

(*a*) 1 c.cm. of brass weighs .... gm. wt. therefore the density of brass is .... gm. per c.cm.[1]

---

[1] Remember that an object which has a *weight* of 17 gm. wt. has a *mass* of 17 gm.

(*b*) 1 c.cm. of copper weighs .... gm. wt., therefore the density of copper is .... gm. per c.cm.
(*c*) 1 c.cm. of aluminium weighs .... gm. wt., therefore the density of aluminium is .... gm. per c.cm.
(*d*) 1 c.cm. of zinc weighs .... gm. wt., therefore the density of zinc is .... gm. per c.cm.
(*e*) 1 c.cm. of wood weighs .... gm. wt., therefore the density of this kind of wood is .... gm. per c.cm.

HOW TO FIND THE DENSITY OF A SOLID

27. Find the volume of the given square wood block (by measurement and calculation) and then weigh it. Use the result to calculate the density of the wood.

Volume of block = ... by ...... by ...... = ... c.cm.
Weight of block = ... gm. wt., so its Mass = ... gm.
Therefore,

density of wood $= \frac{\text{MASS}}{\text{VOLUME}} = \frac{\quad}{\quad} =$ .... gm. per c.cm.

(If different kinds of wood are available, notice the different density of 'soft-woods' and 'hard-woods'.)

HOW TO FIND THE DENSITY OF A LIQUID

28. Find the density of tap-water as follows. Weigh a 100 c.cm. beaker. Carefully measure out 50 c.cm. of tap-water with a pipette into the beaker, and weigh again.

Weight of empty beaker = ... gm. wt.
Weight of beaker and 50 c.cm. of water = ... gm. wt.
Therefore, weight of 50 c.cm. of water = ... gm. wt.

Therefore, density of tap-water at ....° C. $= \frac{\quad}{50}$

= .... gm. per c.cm.

29. Find the density of the given sample of sea-water in the same way.

Weight of empty beaker[1] = ... gm. wt.
Weight of beaker and sea-water = ... gm. wt.
Therefore, weight of 50 c.cm. of sea-water = ... gm. wt.

Therefore, density of sea-water at ....° C. = $\frac{\qquad}{50}$
= .... gm. per c.cm.

WHAT IS THE EFFECT OF TEMPERATURE ON DENSITY?

Solids, liquids and gases all *expand* as they get warmer, i.e. their volume becomes greater. But

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}$$

so that if the volume increases while the mass remains the same, the density will become less. Hence we must be careful to state the temperature at which the density was measured, especially when finding the densities of liquids and gases, e.g. at 4° C., the density of pure water is 1·000 gm. per c.cm.; at 30° C. it is 0·996 gm. per c.cm.; at 40° C. it is 0·992 gm. per c.cm.; and at 80° C., it is 0·972 gm. per c.cm. (Since solids expand much less than liquids for the same rise in temperature, the effect of temperature on their density is so small that we can ignore* it in this course.)

SPECIFIC GRAVITY

Density can be stated in any system of weights and measures, e.g. the density of water is 1 gm. per c.cm. on the Metric System and 62 5 lb. per cu. ft. on the British system. This makes it difficult to *compare* the densities of two substances if they are given in different units. For example, if you are told that the density of alcohol is 0·8 gm. per c.cm. and that the density of kerosene is 50 lb. per cu. ft., you have to do a calculation before you can say whether alcohol is denser than kerosene. For most purposes, it is more convenient, instead of measuring the actual *density* of a substance, to measure its *specific gravity*.†

---

[1] If you use the same beaker as in Ex. 28, there is no need to weigh it empty again.

The specific gravity of a substance is the ratio of the weight of the substance to the weight of an equal volume of water.*

$$\text{SPECIFIC GRAVITY} = \frac{\text{WEIGHT OF SUBSTANCE}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}}$$

Notice that the *specific gravity is a ratio* and is therefore expressed only as a *number*. *Density*, however, must be expressed in *units*, e.g. gm. per c.cm., or lbs. per cu. ft.

Let us suppose that the volume of a body of mass 20 gm. is 10 c.cm. Then its *density* $= \frac{M}{V} = \frac{20 \text{ gm.}}{10 \text{ c.cm.}} = 2$ gm. per c.cm. Its *specific gravity* at 4° C. will be $\frac{20 \text{ gm. wt.}}{10 \text{ gm. wt.}} = 2$, for 10 c.cm. of water at 4° C. has a mass of 10 gm. and weighs 10 gm. wt. Therefore, the specific gravity of a substance at 4° C. is given by the same *number* as its density in gm. per c.cm. [Notice that the density of the body used in this example is 125 lb. per cu. ft., while its specific gravity is 2.]

HOW TO MEASURE THE SPECIFIC GRAVITY OF A LIQUID

30. Weigh a clean, dry, *specific gravity bottle*, together with its stopper. Notice that there is a small hole through the stopper to allow liquid to escape when the stopper is put in, so that the bottle can be filled exactly each time it is used (see Fig. 85). After weighing the empty bottle, fill it with water, put in the stopper, and weigh it again after drying the outside of the bottle very carefully. By subtraction, find how much water the bottle holds. Pour out the water, and wash the bottle with a few c.cm. of the given copper sulphate solution to remove the last of the water. Then fill the bottle with the copper sulphate solution, put in the stopper, dry the outside, and weigh again. (Return the copper sulphate solution to

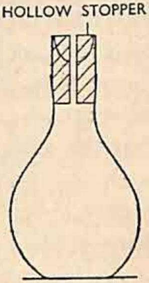

FIG. 85. Specific gravity bottle.

the stock-bottle after the experiment—do not pour it down the sink.)[1]

Weight of specific gravity bottle *empty* = ... gm. wt.
Weight of specific gravity bottle *full of water* = ... gm. wt.
Therefore, *weight of water* = ... gm. wt.
Weight of specific gravity bottle *empty* = ... gm. wt.
Weight of specific gravity bottle *full of copper sulphate solution* = ... gm. wt.
Therefore, *weight of copper sulphate solution* = ... gm. wt.
But,

$$\text{SPECIFIC GRAVITY} = \frac{\text{WEIGHT OF SUBSTANCE}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}} = \underline{\qquad\qquad}$$

Therefore, the specific gravity of this copper sulphate solution. at ....° C., is........

Learning Exercises on the first part of this Chapter will be found on pp. 10–21 of *General Science Workbook I.*

THE PRINCIPLE OF ARCHIMEDES

Archimedes (287–212 B.C.), a Greek mathematician* and engineer who lived at Syracuse, in Sicily, was one of the greatest of the early scientists and he was one of the first to *apply* his knowledge to everyday problems. Hiero, the King of Syracuse, had given some pure gold to a goldsmith* to make a new crown. When the new crown was finished, it weighed the same as the original gold, but the king suspected that the goldsmith had mixed some silver with the gold, and that he had stolen the rest of the gold. He ordered Archimedes to find out whether the crown was made of pure gold or not, without damaging it.

Archimedes was puzzled until, one day as he stepped into his bath, which was completely full of water, he realized that the overflow was equal to the volume of his body, i.e. he displaced an equal volume of water. He realized also that, as gold was more dense than silver, equal *weights* of gold and silver would not displace equal *volumes* of water. So he put the new crown on one pan of a balance and added *pure gold* (lent by the king) to the other pan until the two sides balanced. He then put this equal weight of pure gold into a vessel that was completely full of water, and the gold displaced its own volume of water. He then took out the pure gold and put the crown in the water that was left in the vessel. *Some more water was displaced*, proving that the volume of the crown was greater than that of the same *weight* of pure gold, i.e. the *density* of the crown was *less* than that of pure gold and the goldsmith had cheated the king.

---

[1] This is an example of how you must always try to *avoid waste* of school science materials. Remember that every cent you save in this way will help your school to buy more and better science equipment.*

Later on, Archimedes also noticed that his body felt lighter in water than in air, and by careful reasoning he showed that there was an upward force acting on his body *equal to the weight of water he displaced*. This is now known as '*the Principle of Archimedes*'† and it may be stated as follows:—

When an object is weighed in air and then in a liquid, there seems to be a loss in weight. This seeming loss in weight is equal to the weight of liquid displaced by the object.

Since it also applies to *gases*, a more general way of stating Archimedes' Principle is to say, '*When an object is completely surrounded by a fluid,* there is a force pushing upwards on the object equal to the weight of fluid displaced*'. (The term *fluid* includes both liquids and gases—any matter that *flows*.)

HOW TO TEST THE TRUTH OF ARCHIMEDES' PRINCIPLE

31. Hang a solid body (e.g. a lump of metal, glass, or stone) by a piece of cotton thread from a spring balance and record its weight below. Take an *overflow can*,† put a beaker under its side-tube and pour water into the can until it overflows into the beaker. When the water stops dropping from the side-tube, remove the beaker and in its place put an empty beaker that has been weighed on the

spring balance. Then lower the solid, hanging from the spring balance, into the overflow can until it is completely surrounded by water (but *not* resting on the bottom—see Fig. 86). Read off the new weight of the solid from the spring balance. Then find the weight of the water, displaced by the solid, which overflowed into the weighed beaker.

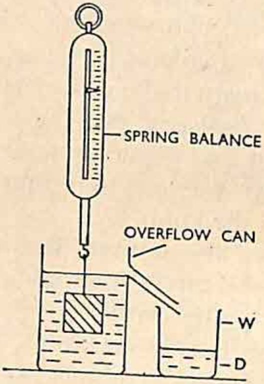

FIG. 86. Testing the truth of Archimedes' principle.

W.	Weighed beaker
D.	Displaced water

Weight of solid in air = ... gm. wt.
Weight of solid in water = ... gm. wt.
Therefore, *seeming loss in weight* = ... gm. wt.
Weight of beaker and water = ... gm. wt.
Weight of empty beaker = ... gm. wt.
Therefore, *weight of water displaced* = ... gm. wt.

Compare this loss in weight of the object when surrounded by water with the weight of water displaced. If they are the same, it shows that *when an object is first weighed in air and then in a liquid, there seems to be a loss in weight equal to the weight of liquid displaced.*

32. Another way of testing the truth of Archimedes' Principle is

to take a metal cylinder and a tube into which it fits exactly, and hang them both from a spring balance as shown in Fig. 87.

Note the weight. .... gm. wt.

Now put a beaker of water under the apparatus and lower the balance until the cylinder is surrounded by water.

What happens? ....

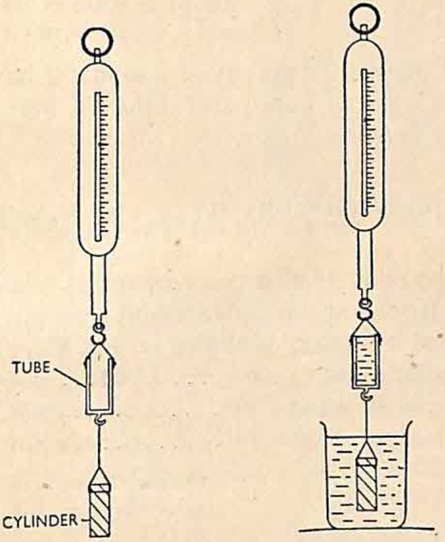

FIG. 87. Another way to test the truth of Archimedes' Principle.

Carefully pour water into the tube (e.g. from a pipette or a wash-bottle†) until the balance reads the same as before.

How much water is needed for this? ....

What is the volume of this water? ....

What do you conclude from this? ....

....

HOW TO FIND SPECIFIC GRAVITY BY USING ARCHIMEDES' PRINCIPLE

Archimedes' Principle can be used to find specific gravity, since

$$\text{SPECIFIC GRAVITY OF SOLID} = \frac{\text{WEIGHT OF SOLID}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}}$$

$$= \frac{\text{WEIGHT OF SOLID}}{\text{WEIGHT OF WATER DISPLACED}}$$

$$= \frac{\text{WEIGHT OF SOLID IN AIR}}{\text{LOSS OF WEIGHT IN WATER}}$$

Hence, to find the specific gravity of a solid, we have only to *weigh the solid in air, then in water, and divide its weight in air by the seeming loss of weight in water.*

HOW TO FIND THE SPECIFIC GRAVITY OF A SOLID, USING ARCHIMEDES' PRINCIPLE

33. Hang the solid (e.g. a piece of metal, glass, or stone) by cotton thread from a spring balance and weigh it, first in air, and then surrounded by water, as shown in Fig. 88.

Weight of solid in air = ... gm. wt.
Weight of solid in water = ... gm. wt.
Therefore, *loss in weight* = ... gm. wt.

But, specific gravity $= \dfrac{\text{WEIGHT OF SOLID IN AIR}}{\text{LOSS OF WEIGHT IN WATER}}$

Therefore, S.G. of solid = ——— = ...

HOW TO FIND THE SPECIFIC GRAVITY OF A LIQUID, USING ARCHIMEDES' PRINCIPLE

If we weigh a solid, first in air and then in water, the seeming loss in weight is the weight of an equal volume of water. If we weigh the solid first in air and then in some other liquid, the second loss in weight is the weight of an equal volume of the second liquid. Dividing one by the other we get the specific gravity of the second liquid.

34. Find the specific gravity of the given common salt solution

in this way, weighing a piece of glass (e.g. a large stopper) first in air, then in water, and then in the salt solution.

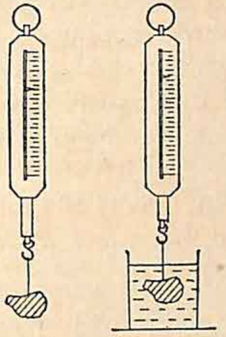

FIG. 88. Finding the specific gravity of a solid or liquid, using Archimedes' Principle.

Weight of glass in air = ... gm. wt.
Weight of glass in water = ... gm. wt.
Therefore, *weight of water displaced* = ... gm. wt.
Weight of glass in air = ... gm. wt.
Weight of glass in solution = ... gm. wt.
Therefore, *weight of solution displaced* = ... gm. wt.

But,

$$\text{SPECIFIC GRAVITY OF SOLUTION} = \frac{\text{WEIGHT OF SOLUTION}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}}$$

$$= \frac{\text{WEIGHT OF SOLUTION DISPLACED}}{\text{WEIGHT OF WATER DISPLACED}}$$

Therefore,
S.G. of salt solution at ...... ° C. = ——— = ...

FLOATING

When an object is surrounded by water (or any other *fluid*) there are two forces acting on the object in opposite directions:—(*a*) its own weight acting downwards, and (*b*) a force equal to the weight of water displaced, pushing upwards. If the downward force is greater than the upward force, then the object will *sink* to the bottom. If the object weighs less than the water it displaces, then the upward force due to the displaced water will push the object to the surface, and part of it will rise out of the water until the upward force is equal to its own weight. This is summed up in the *principle of floating bodies*:—

A floating body sinks until the weight of the fluid displaced by the part below the surface becomes equal to its own weight.

HOW TO TEST THE TRUTH OF THE PRINCIPLE OF FLOATING BODIES

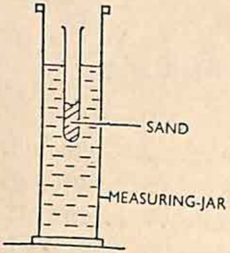

FIG. 89. Principle of floating bodies.

35. Float a test-tube upright in water by pouring into it enough sand to bring the mouth about an inch above the surface. Dry the outside of the tube, being careful not to lose any of the sand, and then weigh it. Record this weight below. Pour about 70 c.cm. of water into a 100-c.cm. measuring cylinder, and read off the volume accurately. Then lower the test-tube gently into the measuring cylinder and read off the new volume, holding the test-tube in the middle of the cylinder with your pencil (see Fig. 89).

Weight of test-tube and sand = ... gm. wt.
Original volume of water in cylinder = ... c.cm.
Volume with test-tube floating in the water = ... c.cm.
Therefore, volume of water displaced by test-tube = ... c.cm.
Therefore, *weight of water displaced by test-tube* = ... gm. wt.

If the weight of this water is equal to the weight of the test-tube and sand it shows that *a floating body displaces its own weight of the fluid in which it floats.*

THE FLOATING OF SHIPS

The last experiment explains the floating of ships. A ship floats at such a depth that the *weight of the ship* is exactly balanced by the upward force due to the *water displaced.* As it is loaded, the ship sinks a little deeper in the water so as to displace enough water to balance this extra load. A steel ship floats because it is hollow and the volume of water that it displaces is very much greater than the volume of the actual steel used in building the ship. Its *average density* is less than the density of water, so in displacing its own *weight* of water it displaces only a fraction of its total *volume.* The '*displacement*'† of a ship is the weight of water that she displaces when floating, i.e. her own *weight*. It is impossible to weigh a big ship directly, but it is fairly easy to find her volume below the water-line. This volume multiplied by the density of the surrounding water gives the mass of the ship, and so its weight, calculated from her *displacement*. The '*tonnage*'† of a ship is the maximum weight of cargo she can safely carry, i.e. the difference between her *displacement* when empty and when fully loaded.

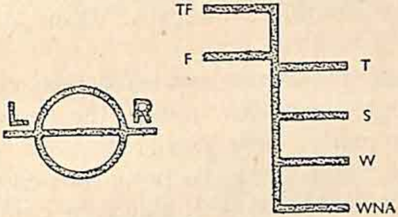

FIG. 90. Plimsoll Mark.

During the nineteenth century, ships were often overloaded until they floated too low in the water to survive rough seas and were easily sunk in a storm. To stop the loss of sailor's lives, a Member of the British Parliament named Plimsoll succeeded in getting a law passed, in 1890, to stop this overloading of ships, and every British merchant ship now has a *Plimsoll Mark*† or *load-line*, on each side of the ship. In Fig. 90, 'LR' means that the load-line has been fixed by Lloyd's Register* of shipping and this is the normal* summer load-line 'S' for sea-water in temperate* regions.

The other marks to the right of the load-line show the maximum depth to which the ship may be loaded (*a*) in tropical fresh-water, 'TF', (*b*) in fresh-water elsewhere, 'F', (*c*) in tropical sea-water, 'T', (*d*) in sea-water, in summer, elsewhere, 'S', (*e*) in sea-water, in winter in the North Atlantic, 'WNA' (when rough seas make it necessary to provide an extra 'margin* of safety'), and (*f*) in sea-water, in winter, elsewhere, 'W'. Notice that more of the ship is below the surface in fresh-water than in sea-water, because sea-water is denser than fresh-water and the same upward force is produced by displacing a smaller volume of sea-water. The summer and winter marks are different because warm water is less dense than cold water.

Submarines† are ships whose average density can be controlled. By letting water into the *ballast* tanks*,* the average density of the submarine can be made a little greater than that of the surrounding water, and the vessel sinks. To bring the vessel to the surface, the water in the ballast tanks is displaced by compressed air until the average density of the submarine becomes less than that of water. When a submarine is under water, it is impossible to keep its average density exactly the same as that of the surrounding water, and it is kept travelling at the required depth by using horizontal rudders.* A bony fish keeps its average density equal to that of the surrounding water by altering the size of its *swim-bladder*, which contains air.

Balloons and *airships* are usually filled with *hydrogen* (whose density is only one-fourteenth that of air), or with *helium* (which is twice as dense as hydrogen). For a balloon to rise in the air, the upward force due to the air displaced by the balloon must be greater than the total weight of the balloon. In Book Two we shall learn that (owing to its compressibility) the air becomes less and less dense as we rise above the Earth's surface. So a balloon stops rising when its total weight becomes equal to that of the displaced air. To rise higher, the weight of the balloon must be reduced by dropping *ballast* (usually in the form of sand). To descend, some hydrogen is released from the gas-bag, thus reducing the volume of the balloon, and at the same time reducing the upward force due to displaced air.

HYDROMETERS

We have seen that the fraction of a floating body that sinks below the surface depends on the density of the liquid. The *hydrometer*,† an instrument for finding the specific gravity of a liquid very quickly, makes use of this fact.

HOW TO SHOW THE PRINCIPLE OF THE HYDROMETER

36. A '*density-rod*' is a very simple kind of hydrometer. It is a waxed wooden rod, weighted at one end to make it float upright.

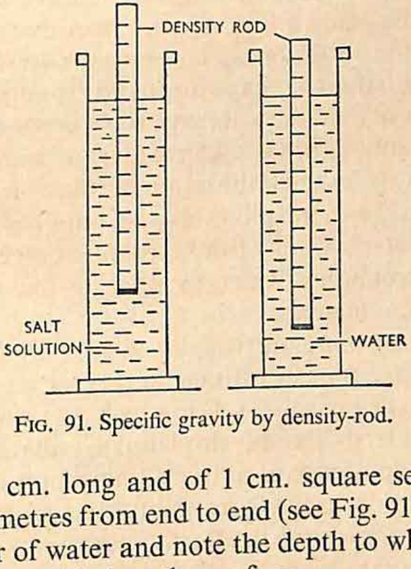

FIG. 91. Specific gravity by density-rod.

It is usually 15 cm. long and of 1 cm. square section, and it is marked in centimetres from end to end (see Fig. 91). Put a density-rod in a cylinder of water and note the depth to which it sinks, i.e. the length of the rod below the surface. .... cm. Since the area of its cross-section is 1 sq. cm., the *volume of water displaced*

= .... c.cm. and since the rod is *floating* in the water, *the weight of this volume of water is equal to the weight of the rod.*

Dry the density-rod and then put it in a cylinder of salt solution. Note the depth to which it sinks. .... cm. Therefore, the *volume of salt solution displaced* = ... c.cm. But since the rod is *floating* in the liquid, *the weight of this displaced salt solution is equal to the weight of the rod.*

We have now found the *volumes* of water and salt solution that have *the same weight*, and from this we can easily find their specific gravities since

$$\text{SPECIFIC GRAVITY OF SOLUTION} = \frac{\text{WEIGHT OF 1 C.CM. OF SOLUTION}[1]}{\text{WEIGHT OF 1 C.CM. OF WATER}}$$

$$= \frac{\text{WEIGHT OF SOLUTION}}{\text{VOLUME OF SOLUTION}} \div \frac{\text{WEIGHT OF WATER}}{\text{VOLUME OF WATER}}$$

But, using the density rod,

$$\text{WEIGHT OF SOLUTION DISPLACED} = \text{WEIGHT OF WATER DISPLACED}$$

Therefore,

$$\text{SPECIFIC GRAVITY OF SOLUTION} = \frac{\text{VOLUME OF WATER DISPLACED}}{\text{VOLUME OF SOLUTION DISPLACED}}$$

$$= \frac{\text{LENGTH OF ROD BELOW SURFACE OF WATER}}{\text{LENGTH OF ROD BELOW SURFACE OF SOLUTION}}$$

Therefore, S.G. of salt solution

(at ...... ° C.) = ———— = ...

HOW PRACTICAL HYDROMETERS ARE USED

A practical *hydrometer*, like the one shown in Fig. 92, works on the same principle as a density rod, but it consists of a glass tube, weighted at its bottom end with mercury or lead, so that it floats upright. To save any calculation, however, the glass tube contains a paper scale marked directly with specific gravities, so that when the instrument is put in pure water, it sinks until the surface of the water is level with the 1·000 mark on the scale. When put in a denser liquid, the hydrometer does not sink so deeply, and the

[1] Compare this definition with the one given earlier (on p. 151) and satisfy yourself that they are the same.

specific gravity of the liquid can be read off directly on the hydrometer scale at the point where the surface of the liquid cuts the stem of the hydrometer.

In everyday life, hydrometers are used for testing milk, for testing the concentration of acid in car batteries, and for finding the amount of alcohol in wines and spirits. Using a hydrometer, the specific gravity can be found very quickly, since it is only necessary to float the instrument in the liquid and read off the specific gravity from the scale. To make the instrument more accurate, the glass tube containing the scale is made very narrow, and so that the hydrometer shall not be so long as to break easily, hydrometers are usually made in sets for measuring different ranges of densities, one instrument leaving off where the next begins. Thus, a set of four hydrometers may read from 0·700 to 1·000; 1·000 to 1·300; 1·300 to 1·600; and 1·600 to 2·000. As all common liquids (except mercury) have specific gravities between 0·7 and 2·0, the decimal-point is usually left out of the figures on commercial hydrometers, so that the above set is marked 700 to 1000; 1000 to 1300; 1300 to 1600; and 1600 to 2000. If you see a bottle in the laboratory labelled 'AMMONIA S.G.900', it contains a solution of ammonia gas in water of specific gravity 0·900.

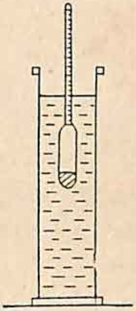
FIG. 92. Hydrometer.

37. Use glass hydrometers to find the specific gravity of the following liquids:—

Specific gravity of *methylated spirit* at . . . . . . °C. = ...
Specific gravity of *saturated salt solution* at . . . . . . °C. = ...
Specific gravity of *saturated calcium chloride solution* at . . . . . . °C. = ...

Examine a *battery hydrometer*. When a *lead accumulator* (e.g. a car battery) is fully charged, the specific gravity of its sulphuric acid rises to over 1·20. If the specific gravity is less than 1·18 the battery needs re-charging. This is the best way of testing a lead accumulator. A battery hydrometer can be made very small, since it is only graduated from S.G. 1·100 to 1·250.

Learning Exercises on the second half of this Chapter will be found on pp. 22–28 of *General Science Workbook I.*

APPENDIX A

GENERAL INSTRUCTIONS FOR SCIENCE CLASSES

1. ADMITTANCE TO SCIENCE ROOMS

No pupil is allowed in any Science Room unless a teacher is present.

2. USE OF LABORATORY MATERIALS

Caution. Laboratory* materials are to be used only in the Science Rooms. They must be used only for the purpose approved by the teacher, and pupils are warned not to go beyond the directions of the teacher in any experiment. Nothing must be taken away from any Science Room. Remember that most chemicals* are poisonous, and that many of them eat away the skin, clothes, and other materials by chemical action. It is therefore necessary to be very careful in using chemicals. Bottles should never be carried by the neck. Always be careful that the name on the bottle is *exactly* the same as that of the substance you require.

3. ACCIDENTS

Any cut, burn, chemical in the mouth or eye, or other accident must be reported *at once* to the teacher. Prompt treatment will save you trouble and pain later. If you get any chemical on the skin or clothes, wash it off *at once* with plenty of water. Anything accidentally taken into the mouth you must spit out *at once* (*do not swallow it*) and the mouth must be washed out with plenty of water. If your clothes ever catch fire, *do not run about*, but roll on the floor until the fire-proof blanket* is brought. (Do not let this frighten you about practical work in science. Very few people have such accidents in well-organized laboratories, but it is always safer to '*Be Prepared*' and to know what to do if accidents happen.)

4. CARE OF SCIENCE ROOMS

One of the most important things that you will learn from your school science course is the value of cleanliness and tidiness in your practical work and also in your everyday life. (In fact, the *way you work* in the Science Rooms is just as important as the facts you learn.) You will expect to find the Science Rooms clean and tidy when you come to science lessons, therefore *you* must leave them equally clean and tidy for the next class after you have finished work. All apparatus must be cleaned and put back in its proper place when practical work is over. Do not put bits of glass, corks, matchsticks, and such articles in drawers or cupboards. Do not use burning pieces of paper for lighting your burner. Let hot articles cool before putting them away.

When you are using a burner, protect the bench beneath with an asbestos* sheet. If anything is too hot to hold in the fingers, put it on this asbestos sheet and not on the bare bench. If you drop any liquid on the bench, wipe it up with a *wet* duster. Solids (e.g. bits of paper, broken glass, matchsticks, etc.) must not be thrown in the sinks,* but must be put in the metal waste-boxes which are provided for this purpose. When you pour acids or other chemicals down the sinks, wash down with plenty of water so as to stop the chemicals from attacking the drains. When emptying gas-troughs,* hold the trough well over the sink: do not let water run down the outside of the sink.

Turn off water-taps and gas-taps when not in use so as to avoid waste. Turn down the flame when you are not going to use the burner for the next few minutes.

Your teacher will show you the proper way to remove the stopper from a bottle. Always see that you replace the stopper in the proper bottle. (Bottles and their stoppers are often marked with a letter or number so that there should be no mistake.) Always pour out of the side *opposite to the label*.

Any breakage or damage must be reported *at once*.

APPENDIX B

SCIENTIFIC APPARATUS AND DIAGRAMS

Before you can start doing woodwork or metal-work in a *workshop* you have to learn the names of your *tools* and how they are used. A *laboratory** is only a special kind of workshop in which you use scientific tools, or *apparatus.** So before you do any work in the laboratory you must learn the names of the apparatus that you will have to use and what the various 'scientific tools' are used for. Since the best way of describing your apparatus is to *draw* it, it is important to start learning, at once, how to make good *scientific diagrams.**

HOW TO MAKE DIAGRAMS

For scientific description, drawing is almost as important as writing, for it is often easier, quicker, and clearer to express a scientific idea in *lines* than in *words*. It is only during the last five or six thousand years that men have learnt to make *written records*. Long before this, however, men were drawing and painting clear pictures on the walls of caves. If we are sufficiently skilled in the use of *language*, we can describe most things in *words* (either spoken or written), but almost every account of scientific work and ideas is improved, and made easier to understand, with the help of a *drawing*, a *sketch*,* or a *diagram*.

A *drawing* is intended to show (usually in outline) the *exact shape of some particular object* and the relative* size and position of its parts. Such *drawings*, however, belong more to your art lessons than to your science lessons.

A *sketch* represents, in outline, *a typical* example* rather than one particular object. So a sketch gives the *general* shapes and positions of the parts you want to bring out, and *it omits all the other details* that you do not need to explain for this particular purpose. Such *sketches* are more helpful than drawings to scientific description and they save a lot of writing.

A *diagram* represents an *idea* rather than any particular object. It is not intended to give an accurate representation of size and shape, but a diagram merely shows, *at a glance*,* the *essential** parts and processes,* and how they are related.

In this book there are about 75 such *diagrams* (with about 35 *sketches*), and as you study Book One you will realize how they help you to understand the printed explanation. Similar diagrams will be equally helpful when you have to *record* your own practical work or pass on your scientific knowledge to others (including, at a later stage, examiners), so training and practice in diagram-making will be a very important part of your school science course.

Most of the diagrams reproduced in this book were drawn by the author's old pupil, Leong Pak Cheong, when he was just 'starting science' (as you are now). But Leong Pak Cheong had no printed textbook with ready-made diagrams in it. At the end of each lesson, he got a type-written sheet (which he put into his loose-leaf binder) and *he made his own diagrams and sketches* lesson by lesson. In this way, he gradually built up his own illustrated textbook and (although Leong Pak Cheong is now a well-qualified and experienced professional scientist) in revising* his diagrams for this new edition he has not had to make many alterations* to the originals that he drew when he was at school. So with the help of this textbook you should be able to follow Leong Pak Cheong's example in the art of diagram-making.

The first thing to realize is that a good diagram is *large*,[1] *clear*, and *simple*, with no unnecessary shading and not a single line that does not mean something. Such a diagram is easy to look at, and is usually easy to draw. Wherever possible, your diagram should represent a vertical* *section** through the apparatus, so as to show '*how it works*'. *Print* the labels* clearly (*outside* the diagram as far as possible) with a straight line pointer going right on to touch the exact part you are naming.

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[1] To save valuable space (and thus keep down the cost of these textbooks) most of the diagrams have been *reduced* in size from Leong Pak Cheong's originals.

Your teacher will now explain to you the commonest scientific tools that you will use in the laboratory and, at the same time, you should practise drawing them diagrammatically.

BUNSEN BURNER

We nearly always use a Bunsen burner when we want to heat anything in the laboratory. It gets its name from its inventor, the German chemist* Bunsen, and it burns .... gas (see Fig. 93). If we unscrew the burner-tube, we see a small *jet** in the base of the burner, through which the gas passes. A tap controls the flow of gas. If we put back the burner-tube, close the *air-holes*, and light the gas, we get a white or yellow flame (a *luminous** flame) which is not very hot, and which is rather smoky. If we open the air-holes gradually we notice that the flame becomes *non-luminous*,* cleaner, and much hotter. This is the *Bunsen flame* that we use for most of our work, and you must practise controlling the gas and air until you can get this hot, clean flame. A large *wind-shield* is useful for sheltering the flame from the wind when the laboratory windows are wide open.

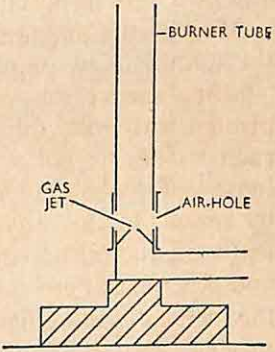

FIG. 93. Bunsen burner.

The diagram in Fig. 93 shows a Bunsen burner in vertical section. There are many shapes and sizes of Bunsen burners, but *they all work on the same principle** (as described above). So whenever we have to represent a Bunsen burner (of any pattern) we draw it like Fig. 93, because this is the quickest, easiest, and clearest way of showing how such a burner works.

In most of your diagrams showing experiments in which a Bunsen burner supplies heat, there is no need to draw the entire burner every time, but only the top end of the burner tube and the flame, as shown in Figs. 95 and 96. When the apparatus is heated only gently, holding the Bunsen burner in your hand and moving the flame from side to side, then draw the burner tube at an angle, as shown in Fig. 15.

TRIPOD STAND

The *tripod* stand* is a firm and steady support, of fixed height. Having three legs, it always stands firmly on any surface, even if its three feet are not quite level. A *flame-steadier* is a tripod stand combined with a small cylindrical* wind-shield.

To show a tripod stand in a diagram, it is not necessary to draw all three legs (see Fig. 95), and although most tripods have their legs sloping outwards (so that they stand more firmly) it is much easier to draw them with vertical legs.

RETORT STAND, RING AND CLAMP

A *retort* stand* provides support at different heights by means of movable *retort rings* and *retort clamps** which are fixed to the stand by *cross-head clamps*. A retort stand is not so steady a support as a tripod.

In art lessons, it would take you a long time to make *drawings* of a retort clamp, a retort ring, and a cross-head clamp, so when showing them in a *diagram* you should simplify them down to the bare essentials (as in Fig. 94). In a complicated diagram (e.g. Fig. 66) we sometimes omit retort stands and clamps if they hide more essential parts. So when you see apparatus that appears to be float-

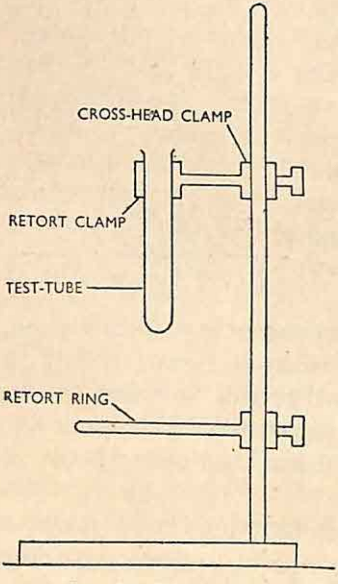

FIG. 94. Retort stand.

ing in the air, you will know why supports and clamps have been omitted from the diagram.

The jaws of retort clamps are lined with soft cork, so you must never let your Bunsen flame touch a retort clamp.

WIRE GAUZE

A *wire gauze** is made of tinned iron wire and is put between the burner and glass or porcelain* vessels to spread out the heat of the flame evenly over the bottom of the vessel. This lessens the risk of the vessel breaking. In your diagrams, a wire gauze can be shown (in section) as a single straight line, labelled at one side.

SAND BATH

A *sand bath* is a shallow iron dish, filled with sand, which is put between the flame and the vessel that is being heated (see Fig. 95). A sand bath serves the same purpose as a wire gauze, but gives more protection and allows more gentle heating. Do not fill your sand bath from laboratory fire-buckets* that contain sand for putting out oil fires.

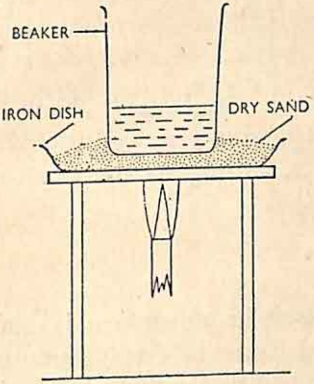

FIG. 95. Sand bath.

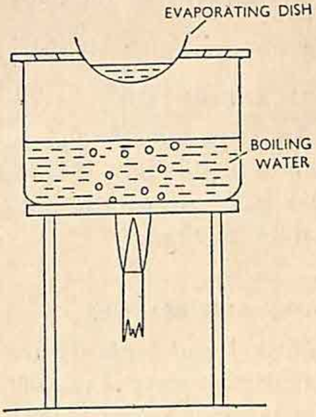

FIG. 96. Water bath.

WATER BATH

A *water bath* is a vessel in which water is boiled over a burner, and any other vessel that is to be heated *very gently* is put on top of the water bath, where it is heated by the steam from the boiling water (see Fig. 96). This gives even more gentle heating than the sand bath, because the temperature cannot rise above 100° C. (the temperature of boiling water).

In any experiment that involves* using a water bath, start heating the water before you do anything else. By *planning* your practical work in this way, you will save a great deal of time throughout this science course.

FIRECLAY TRIANGLE

The *fireclay*† *triangle** is a support for a small article like a crucible† when it is to be heated very strongly in the Bunsen flame. It is an iron wire triangle covered with fireclay (or pipeclay) tubes.

CRUCIBLE AND LID

A *crucible* is a small vessel made of thin *porcelain*. It can be heated directly by the flame, without using a wire gauze or sand bath.

EVAPORATING DISH

An *evaporating** *dish* is a porcelain vessel used chiefly for evaporating liquids. It is usually heated over a wire gauze, over a sand bath, or over a water bath, according to the degree of heating required.

FLASKS AND BEAKERS

Flasks† and *beakers*† are glass vessels in which liquids can be heated. The glass is usually protected from the direct flame by a wire gauze or a sand bath. Flasks can be fitted with corks, beakers cannot. Fig. 98 shows the easiest way to draw the neck of a flask fitted with a cork carrying a glass tube. Notice that although corks are always wider at one end than the other, it is much quicker and easier to draw them with parallel* sides.

TEST-TUBES

Test-tubes† are thin glass vessels for small-scale experiments when only small quantities of material are required. They may be heated directly by the flame if they are kept moving, and if the flame is not allowed to touch the glass above the level of the liquid in the tube. Dirty test-tubes are cleaned with the *test-tube brush*, and are left to dry on the draining-pegs* in the *test-tube stand*. Solids that are to be strongly heated are usually put in *hard glass test-tubes*. 'Hard' glass is *potash glass*,† which has a higher *melting-point* (i.e. it is 'harder' to melt) than ordinary 'soft' glass (*soda glass*)†, which softens and melts at a lower temperature.

CRUCIBLE TONGS

Crucible tongs† are for holding hot crucibles and lids, but *not for holding test-tubes*. (If a test-tube becomes too hot to hold with the fingers, make a test-tube holder from a piece of neatly folded paper, as shown by your teacher.)

DESICCATOR

A *desiccator*† is a thick glass vessel, fitted with a large, air-tight lid coated with vaseline (petroleum jelly)† where it fits on the lower part, which contains *fused calcium chloride*,† a substance that takes up water-vapour* (see Fig. 97). This keeps the air inside the desiccator quite dry, and anything put inside the desiccator will remain dry. Inside some desiccators is a piece of paper that has been soaked in *cobalt chloride*† solution and then dried. When the air

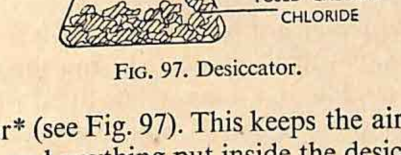

FIG. 97. Desiccator.

inside the desiccator is quite dry, the cobalt chloride paper is *blue*, but if the air becomes damp, then the paper turns *red*. (This means that fresh calcium chloride is needed or that the lid of the desiccator has not been closed properly.)

WASH BOTTLE

A *wash bottle*† is a glass flask or bottle fitted with a cork carrying two bent glass tubes (see Fig. 98). One of these tubes is fitted with a jet, while the other is used to blow in air from the mouth when a stream of water is needed from the jet. A wash bottle usually contains *distilled* water* (i.e. pure water) and is a convenient means of supplying small quantities of water. Your teacher will show you how to get (i) a more rapid stream, (ii) single drops of water, from a wash bottle. In Fig. 98, notice how we represent water (and all other liquids except mercury) by parallel horizontal broken lines.

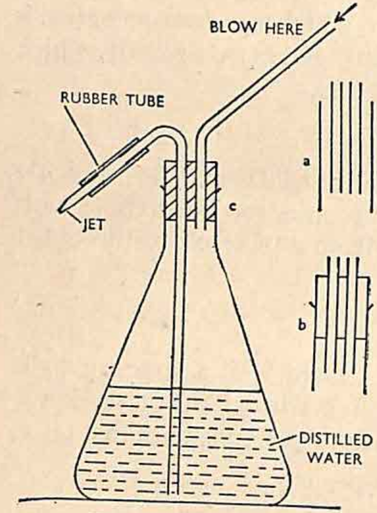

FIG. 98. Wash bottle.

Nowadays, wash bottles are often made of plastic* material.

CORK BORERS

Cork borers† are brass or steel tubes with one end sharpened for boring* corks. The cork that is to be bored is first softened by rolling it on the floor under the foot. A cork borer is then chosen which is *slightly smaller* than the tube for which the cork is being bored. The cork borer is wetted and screwed into the cork, starting from each end in turn. When boring *rubber* corks, the cork borer is first wetted with sodium hydroxide† solution.

GAS TROUGH

The *gas trough*† is a large earthenware* trough used for collecting gases over water in *gas-jars* of thick glass (see Fig. 99). A *gas-jar stand* is sometimes put in the gas trough for supporting the inverted* gas-jar (see Fig. 17). When full, the mouth of the gas-jar is closed by a glass *gas-jar cover*, which is roughened on one side. Fig. 99 shows the easiest way to represent a gas-jar (even when a milk-bottle is used for this purpose).

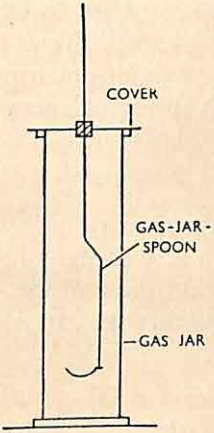

FIG. 99. Gas-jar.

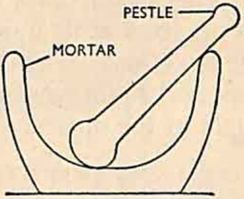

FIG. 100. Pestle and mortar.

OTHER APPARATUS

The *blow-pipe* is used for giving a small, but very hot, flame. The *gas-jar spoon* is for holding substances that are to be burnt in a jar of gas (see Fig. 99). The *triangular file** is for scratching glass tubes and rods before breaking them off, while the *round file* is for enlarging holes in corks when too small a cork-borer has been used, by mistake. The *pestle*† and *mortar*† are for crushing and powdering solids (see Fig. 100). The *spatula*† is for picking up small quantities of solid chemicals.

APPENDIX C

WEIGHING

In everyday life, many things are bought and sold by weight, hence scales, spring balances, and other instruments for weighing are common objects. In science lessons, too, we have to do a lot of weighing, and as we usually want to weigh small things accurately* we use especially delicate and accurate weighing instruments. In our early work in science, we weigh with spring balances as far as possible, so as to save time.

THE SPRING BALANCE

The spring balances we use for much of our work consist of a fine spring, fixed at its upper end, and with a scale-pan† hanging from its lower end. When an object is put on the pan the spring stretches, and by measuring how far it stretches we can measure the weight of the object.

RULES FOR USING DELICATE SPRING BALANCES[1]

(1) The spring balance shown in Fig. 101 is a very delicate instrument and must always be handled *very carefully*.

(2) The only part of the balance you may touch is the pan.*

(3) Do not let go of the pan suddenly, but hold your left forefinger against it while you put anything on and while you take anything off the pan.

(4) See that the spring is hanging freely in the middle of the glass tube. (If it touches the side of the tube anywhere, tell the teacher and he will put it right with the levelling-screws†.)

(5) See that the scale-reading is zero when there is nothing on the pan, sighting on the metal disc.* Raise or lower your head

---

[1] Detailed instructions for making these delicate spring balances are given in the third edition of the Teacher's Handbook.

until the disc is in line with its reflection in the mirror.* Your eye is then on exactly the same level as the disc. Keep your eye in this position while you read off the weight on the paper scale. (If the unloaded reading is not zero, either apply a zero correction or tell your teacher and he will adjust* it to zero.)

(6) See that the object to be weighed is *clean*, *dry*, and *cool*. Steadying the pan with your left forefinger, put the object in the *middle of the pan* and lower the pan gently, steadying it underneath with your finger until the spring is fully stretched.

(7) When you have finished weighing, hold down the pan with your left forefinger while you remove the object, and allow the pan to rise *gently* to its original position.

(8) If there is a wind, close the glass door before reading the weight.

(9) Use decimals* and *not* fractions.*

THE SCIENTIFIC BALANCE

Examine a scientific balance and notice that it consists of a *beam*† and two *scale pans*, the beam being balanced at its mid-point on a *knife-edge*[1] (see Fig. 102). The scale-pans also hang on smaller knife-edges near the ends of the beam by means of '*stirrups*'.*

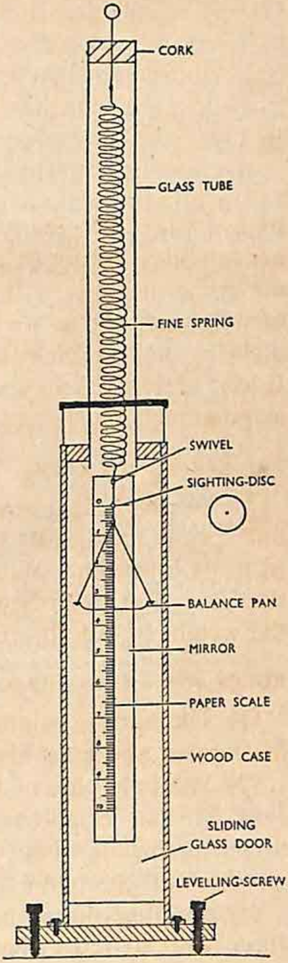

FIG. 101. Delicate spring balance.

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[1] In cheap balances, the knife-edges are made of steel, but more expensive balances use *agate*†, a hard, quartz-like stone. Agate does not rust like steel, but it is more easily broken if the balance is not handled *very gently*.

When the balance is not in use, the beam does not rest on its knife-edge but on the *beam supports*, while the scale-pans rest on the base-board. When the handle in front of the base-board is turned to the right, the beam is raised by the arrangement shown in Fig. 103. The beam must always be raised and lowered *gently* to avoid damaging the knife-edges, and nothing must be put on, or taken off, the scale-pans unless the beam is lowered. The small *adjusting-screws*† at the ends of the beam are for adjusting the balance when one side is slightly heavier than the other. The *levelling-screws* at the front corners of the base-board are for setting the balance perfectly level, with the *pillar*† vertical, as shown by the *plumb-line*.†

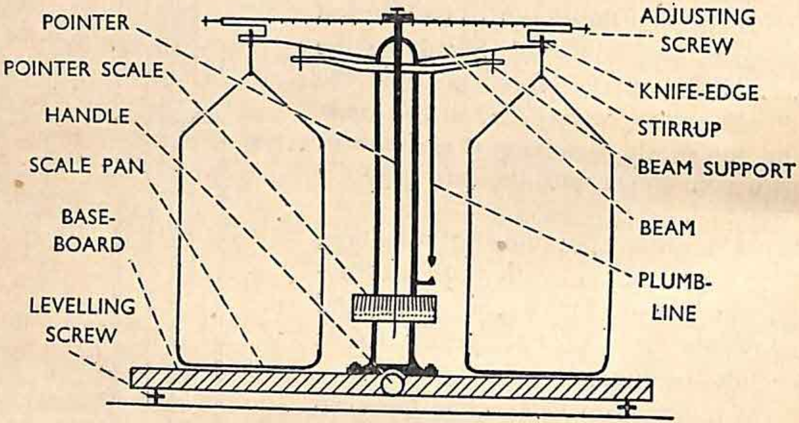

FIG. 102. Balance.

For accurate weighing, the balance is kept in a *balance-case* fitted with a sliding glass door in front to keep out currents of air when the beam is swinging. It is important to raise and lower the sliding door *gently*, so as to avoid shaking the balance. The door is always kept closed when the balance is not in use.

THE WEIGHTS

The weights used for scientific work are those of the Metric System.† The unit we use is the *gram*, and weights are always written down as grams and *decimals* of a gram. To save time and trouble, each weight has its own place in the box, and *you must always put each weight back in its proper place after use.* The weights must always be kept the *right way up* and the *right way round* so that their numbers can be read easily. Always lift the weights with the *forceps** and *never* with the fingers: fingering would soon change their weight and make accurate weighing impossible. (One of the quickest ways of judging the standard of work in a school laboratory is to examine the balances and weights: if these are badly kept, then the standard of all the practical work is almost certainly low.)

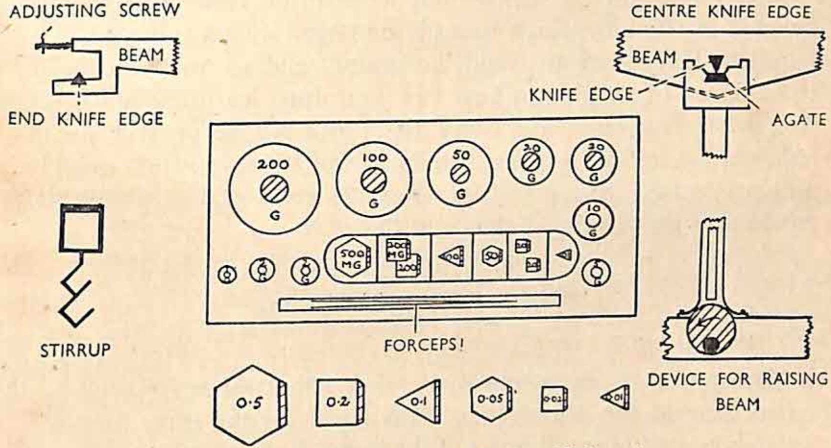

Fig. 103. Set of weights (and details of balance).

Examine a box of weights and notice that the weights are of two kinds, the heavier ones (1 gm. and upwards) being made of brass, and the smaller ones (less than 1 gm.) of nickel, aluminium, or silver (see Fig. 103). These smaller weights may be marked either (*a*) in decimals of a gram, i.e. 0·5 gm., 0·2 gm., 0·1 gm., 0·05 gm., 0·02 gm., 0·01 gm., or (*b*) in milligrams,† i.e. 500, 200, 100, 50, 20, 10. (The latter system has the advantage that the smallest weights bear the smallest number of figures.) To remove the piece of glass that covers the smaller weights, press down with your left forefinger on the left-hand end of the glass, and then remove it with your right hand. (Forceps must *not* be used for this.) To pick up the brass weights (1 gm. and upwards), hold the forceps with their points *upward*. For the smaller weights, turn the points *downward* and lift by holding the upturned corner of the weight.

It is important to realize that a scientific balance is a very delicate instrument which is easily damaged unless very carefully handled. If you are to weigh accurately and without damaging the balance or weights in any way, you must learn the following *Rules for Weighing* and carry them out whenever you use a balance. By following these rules you will learn to weigh quickly and accurately. Every trained scientific worker throughout the world uses this kind of balance in this way.

RULES FOR WEIGHING

(A) THE BALANCE

(1) See that *the base-board is level* and that *the pillar is upright* by looking at the plumb-line. (It is usual for the three feet of a balance to rest in small holes in the bottom of the balance case. If the balance is always kept in this same position it will not be necessary to readjust the levelling screws every time the balance is used.)

(2) See that *the stirrups are resting on their knife-edges* and that *the centre of the beam is in place over the central knife-edge*.

(3) See that *the balance is accurate*, i.e. gently raise the beam and see whether the pointer swings an equal number of divisions on each side of the middle line on the pointer-scale. (If it does not, tell your teacher. Do not try to put it right yourself.) If your balance is in a case, nearly close the door, leaving an opening wide enough to put your hand through to turn the handle (unless the handle is outside the balance case).

(4) Gently *lower the beam before putting anything on, or taking anything off, the scale-pans.*

(B) THE OBJECT TO BE WEIGHED

(5) See that the object which is to be weighed is *clean*, *dry*, and *cool.* Chemicals must not be put on the bare scale-pan.

(6) Put the object that is to be weighed *in the middle* of the *left-hand scale-pan.*

(C) THE WEIGHTS

(7) Lift the weights with the *forceps*, and *never* with the fingers. Put them either on the right-hand scale-pan or in the box, and *nowhere else.*

(8) Put the weights on the *right-hand pan*, the right side up and the right way round, so that their numbers can be read easily. Keep the biggest weights in the middle of the pan.

(9) Start with a weight that is too big. Then *lower the beam*, remove the weight, and try the next smaller weight, thus working through all the weights one by one until the pointer swings an equal number of divisions on each side of the middle line on the pointer-scale when the balance-case is closed.

(10) Add up the weights on the pan and write down the total in your book. Check the weights by noting the empty spaces in the box. Then return the weights to the box in the same order, starting with the biggest. Add up the weights once more as you put them back in the box (being careful to put them the right side up and the right way round). In this way, you check the weight three times. (The commonest mistakes in weighing are made in counting the weights.)

All these instructions sound very complicated, but they are easily remembered after a little practice. The balance is the most delicate and accurate measuring instrument that you will use in this science course and it is worth while learning to use it properly.

APPENDIX D

ACCURACY

A very important part of your practical training during this science course is the proper use of figures in stating the results of your experiments. First of all, you must *always use decimals** and not fractions.* In using decimals for practical purposes, you must learn the proper use of 0's. Many people think that 1 in., 1·0 in., 1·00 in., and 1·000 in., all mean the same thing, and that the 0's do not matter. They *do* matter. 1 in. means a length greater than 0·5 in. and less than 1·5 in., and that the length is accurate* only to the nearest inch, i.e. it was measured very roughly, possibly from the width of a finger. 1·0 in. means a length greater than 0·95 in. and less than 1·05 in., and that the length is accurate to one-tenth of an inch, i.e. the length was measured more carefully, using a ruler marked in inches and tenths of an inch. 1·00 in. means a length greater than 0·995 in. and less than 1·005 in., and must have been measured still more carefully, probably with the *vernier calipers*† (see p. 136 and Fig. 77). 1·00 in. is accurate to one-hundredth of an inch. 1·000 in. means a length greater than 0·9995 in. and less than 1·0005 in., i.e. the length is accurate to one-thousandth of an inch and was probably measured with a *micrometer screw-gauge*† (see p. 137 and Fig. 78).

Notice that every figure has a definite* meaning and tells us the *degree of accuracy* of the measurement. To take another example:—25 gm. is the sort of result you could get by weighing on a cheap 100-gm. spring balance, when the pointer is between 24 and 26, but nearer to 25 than either. This figure has an accuracy of 1 part in 25. On the other hand, 25·0000 gm. shows that the weighing was done very carefully indeed, on a very delicate and expensive scientific balance, using a very accurate set of weights.

25·0000 gm. has an accuracy of 1 part in 250,000, because this figure means that the weight is between 24·9999 gm. and 25·0001 gm., but nearer to 25·0000 gm. than either. This represents a very high degree of accuracy: about the same as that of a clock which gains or loses only one second in three days.

You must always be careful, therefore, never to put more figures in your result than you are sure about, e.g. in your first exercise on the measurement of length (see p. 131), using a ruler marked in inches and tenths, and also in centimetres and millimetres, if you find that a line 7·00 in. long measures 17·8 cm., do not say, 'Therefore, 1 inch = 2·542857 cm.' This would be telling a *lie*, because you are pretending that you can measure more accurately with an ordinary ruler than a very highly trained and skilled scientist using the finest measuring instruments in the world! Using a ruler, you cannot be sure of more than the first three figures, so leave your result as '1 inch = 2·54 cm.'

When working out results from actual measurements, the degree of accuracy of your result must be similar to the degree of accuracy of your measurements. The accuracy of these measurements depends on the error due to the measuring instrument and to the lack of skill in the user. Remember that 'the strength of a chain is the strength of its weakest link',* e.g. if you measure the sides of a rectangle and find them to be 2·34 in. and 1·23 in., multiplying these two numbers together you get 2·8782 sq. in. as the area of this rectangle, but this figure is accurate to 1 part in 28,782 while your actual measurements were accurate to 1 part in 234 and 1 part in 123. So the last two figures of your product 2·8782 are worthless and must be left out if your result is to be a true statement.

In leaving out figures of whose accuracy you are doubtful, *if the first figure to be left out is a 5 or over, add 1 to the last figure kept in your result*. The area of the above rectangle, therefore, should be given as 2·88 sq. in. (This result has a degree of accuracy of 1 part in 288, which is similar to the degree of accuracy of your measurements.)

Notice that 'the number of decimal places' in a result is not the same thing as its 'degree of accuracy', e.g. 0·5 has the same degree of accuracy as 0·05 or 0·005, i.e. 1 part in 5. Hence it is *the number of significant* figures* that matters in practical work and not the number of decimal places. As a rough guide, most of your final results in the practical work of this science course should be given to not more than *three significant figures*, as this represents the highest degree of accuracy you are likely to reach in most of your experiments. (So you should use $\pi = 3{\cdot}14$ and not 3·1416.) In counting the number of significant figures, take no notice of 0's before the decimal point or before the first significant figure, e.g. 5·6, 0·56, 0·056, 0·0056 and 0·00056 all have two significant figures. If your result comes out 0·56 in. exactly, and your measurements justify* three significant figures, then add a 0 and give your result as 0·560 in. This shows that the measurement is accurate to one-thousandth of an inch.

You will also notice that when a number is less than one, we always put a 0 in front of the decimal point, e.g. 0·5 in., or 0·234 gm. This is very useful in drawing attention to this important little dot, especially during practical work, when you are doing an experiment and recording results at the same time (a very different business from sitting quietly at a desk in an arithmetic lesson). Practical men, whose living depends on not making mistakes with their figures, always use this 0 in front of the decimal point.

Note. The student should not part with this book. In studying Books II–IV he will want to refer back to the Glossary and to the Technical Terms marked with a dagger sign (†) in the Index.

GLOSSARY

(Simple definitions of general-purpose words in the text that are not included in the standard vocabulary on which the Course in based.)

abnormal, not *normal*, 44
absorb, take in or suck up, 46
accurate, exact, 4; also *n. accuracy*, 182
acute (angle), (angle of) less than 90°, 70
adjust, regulate or arrange suitably, *alter* slightly, 109, 142
agriculture, cultivation of the soil, 127
alter (*v.*), *alteration* (*n.*), change, make or become different, 168
analyse, separate into simpler parts; find out the elements† or *constituents* of, 48
anhydrous, without water, 44
apparatus, tools, vessels, machines, *etc.*, required for doing something, 167
approximate, not exact, 22
arrow, →, 37
asbestos, *mineral fibre* used for making fire-resisting materials, 166
axle, bar or rod on which a wheel *revolves*, 131

ballast, heavy material (*e.g.* stone) put in ship when sailing without cargo, 160
ball-bearings, small steel balls on which *e.g.* a bicycle wheel *revolves*, 134
balloon, air-tight bag usually filled with a gas that is lighter than air, 19
bench, a strong work-table, 116
biology, science of life of animals and plants, 59
biologist, person skilled and well-informed in *biology*, 59
blanket, large woollen bed-covering, 165
bore (*v.*), make a hole, 88
bubble (*n.*), hollow ball of liquid enclosing air or some other gas; also *v.*, 1
bucket, container for carrying water by hand, 171
bulb, roundish swelling (*e.g.* at end of glass tube); (here) a plant part of this shape, 19
buttress (*n.*), support built against the side of a wall; (here) a similar natural support to the trunk of a tree, 90

candle, a stick of wax, *etc.*, formed round twisted or woven *thread* for giving artificial light, 5

chemical (*adj.*), of or made by *chemistry*, 8; (*n.*) any substance obtained by or used in *chemistry*, 165
chemist, person skilled in *chemistry*, the science of the behaviour of chemical elements† in their various *combinations*, 38,
circulation, movement in a circle or round and round, returning always to starting-point, 65, 107
circumference, line enclosing circle, 131
clamp (*n.*), *apparatus* for holding something in one position, tightened by screw or spring, also *v.*, 170
clasp (*v.*), hold closely, 95
classify (*v.*), *classification* (*n.*), arrange(ment) in classes, xi, 22
clip (*n.*), small *apparatus* for holding things together, usually tightened by a spring, 3
coil (*n.*), length of wire, rope, *etc.*, arranged *spirally* in circles, 25
column, long upright *cylinder* of stone, *etc.*, supporting a building; anything of that shape or purpose, 87
combine (*v.*), join together to form a *chemical* compound†, 12
complex, made up of parts, 31
compress (*v.*), make smaller by pressure, 24
conclude (*v.*), *conclusion* (*n.*), judge(ment), 10
condense, change from *vapour* to liquid, 19
conduct (*v.*), (here) carry electric current, 114
constituents (*n.*), parts making up the whole, 18
contact (*n.*), state of touching; *in contact*, touching, 29
contract (*v.*), become or make smaller, 8
correspond (*v.*), (here) agree in kind, be similar, 127
crude (*adj.*), in a natural or raw state, 36
crust, hard outer part of bread, Earth, *etc.*, 22
cube, solid with six equal square faces or sides; *cubic* (*adj.*), to do with a cube, 129, 2
cycle (*n.*), complete *series* of events that repeats itself in the same order, 67
cylinder, solid or hollow object shaped like a roller, 4

decimal, of tenths or in tens, 130
decolorize, remove colour, make colourless, 109
decompose, (cause to) split up into simpler substances, decay, 22
define, give exact meaning to or of; *definition* (*n.*), exact meaning, 22, 128
definite, within exact or *defined* limits, *distinct*, 23
demonstrate, describe and explain with help of experiments, 9
deposit (*v.*), lay down something in a place; (*n.*), layer of matter *deposited*, 42
design, plan, 143

device, invention; apparatus *designed* for a particular purpose, 135
dew, tiny drops of water formed on cold surface by *condensation* of water-*vapour*, 7
diagram, simple outline drawing, 1, 167
diameter, line drawn across circle through its centre, 133
disc, thin circular plate, such as a round coin, 133
displace, take place of, drive out, 2
dissect, cut up (plant or animal), take to pieces and examine, 73
distil, make pure by turning liquid into vapour and then *condensing* the vapour again, 36
distillate (*n.*), product of *distillation*, 111, 36
distinct, plain, separate, unlike, *definite*, 4
drain (*v.*), carry away water by a channel or *drain* (*n.*); *drainage* (*n.*), what has been *drained*, 80, 104
dye (*n.*), colouring-matter that can be taken up and held by other materials, changing their colour, 52

e.g. (Latin, *exempli gratia*), for example, 23
etc. (Latin, *et cetera*), and the rest, and so on, 40
earthenware, article made of baked clay, 175
elbow, outer part of middle joint of arm, 127
element, substance that has never been split up into two or more simpler substances by *chemical* action, 22
elementary, simple, not advanced, 145
enable, make able, 119
equation, statement that two quantities are equal (*e.g.* $9 + 3 = 12$), 37
Equator, line on map encircling the Earth, halfway between the two Poles, 129
equipment, (here) *apparatus* and materials, 152
equivalent, equal in value (to), 129
essential, necessary, most important, 18
estimate (*v.*), form a judgement of number, amount, *etc.*; (*n.*), quantity thus arrived at, 141
evaporate, change into *vapour* or gas without boiling, 39
eventually, *finally* resulting, 42
exert, bring into use, use strength to do something, 80
expand, increase in size, swell, 6
expire, breathe out, 54
expose, uncover, bring to view, 17
extent, length, *etc.*, to which a thing extends, 19
extract (*v.*), take out by force; (*n.*) preparation of a substance in concentrated† form, 36
eye-brow, curved *patch* of hair above eye, 100

fibre, *fibrous*, thread, threadlike, 77
file (*v.*), scrape with roughened steel tool or *file* (*n.*); (*n.*) *filings*, *particles* scraped off by *file*, 27, 175
filter (*n.*), *apparatus* for freeing a liquid from solid *particles* held by it *in suspension*; *filtrate*, the clear liquid after *suspended particles* have been *filtered* from it, 34, 39
final, *finally*, at the end, coming last, *eventually*, 6
firework, *device* for producing pleasing effect by flame or explosion, 48
fluid, material that flows, *i.e.* liquid or gas, not solid, 153
forceps, pinchers (or pincers) for picking up small things, 78
formula, rule or fact expressed by signs or figures, 37
fraction, number that is not a whole number, *e.g.* $\frac{1}{2}$, $\frac{3}{4}$ *etc.*, 8
fractional (*distillation*), separating (by *distillation*) into *fractions* having different properties, 112
fuel, material for fires (*e.g.* coal, wood, oil), 8
funnel, Y-shaped vessel for *filtering* or for pouring liquid into a small opening, 1, Fig. 2
furrow, long narrow channel as made by a plough, 127
fuse (*v.*), melt by heating, 13

gauge, instrument for measuring *accurately*, 137
gauze, thin closely woven net of wire, cotton, silk, *etc.*, 34
geometry, science of lines, surfaces and solids; *geometrical* (*adj.*), of *geometry*, 42
germinate, begin to grow from seed, 63
glance (*n.*), a quick look, 168
glowing, red-hot, burning slowly and without flame, 26
goad, pointed stick for urging cattle, 127
goldsmith, man who makes articles of gold, 152
graduated, marked out in parts, 140
graph, *diagram* showing relation between two *variable* quantities, 41
gravel, small stones, very coarse sand, 109

hail (*n.*), frozen water *vapour* falling like frozen rain-drops or *hailstones*, 106
hence, therefore, as a result of, 2

i.e. (Latin, *id est*), that is to say, 39
ignore, take no notice of, do not consider, 139
individual (*adj.*), single; (*n.*), one single person, 59
inorganic, of *mineral* origin; not belonging to the very large class of *organic* carbon compounds†, 103
interval, time or space between one event or object and another, 95

invert, turn upside down, 5
invisible, that cannot be seen, 2
involved, made necessary; included, 130

jar (*n.*), deep round vessel of thick glass, 141
jet, stream of water or gas shot out through a small opening; the narrow end of the tube through which a jet comes, 119
jungle, thick tropical forest, 92
justify, be good reason for, 184

label (*n.*), piece of paper fastened to an object giving its name or other particulars; (*v.*), fasten a label to, 43, 168
laboratory, science workroom, 15, 167
layer, thickness of matter, especially one of several, laid over a surface, 56
lens, glass giving a larger or smaller view of an object, 33
liberate, set free, 48
link, one ring or *loop* of a chain, 183
loop, closed figure made by curve that crosses itself, see Fig. 3, p. 3
lubricate, make smooth or slippery with oil, *etc.*, 112
luminous, bright, giving out light, 15, 169
lungs, the two air-bags in the chest, used in breathing, 56

margin (here), extra amount over and above what is necessary, 160
mathematician, person skilled in *mathematics*, the science of space and number, 152
maximum, greatest possible quantity or size, 109
micro- (Greek, *mikros*), prefix meaning 'very small'; on a small scale; *microscope*, instrument using *lenses* to enlarge the appearance of very small, or *microscopic*, objects, 80; *micrometer*, instrument for *accurate* measurement of small lengths, 138
mineral (*adj.* and *n.*), (*inorganic* substance) obtained from the earth, not *organic*, 89
minus, the sign — for *subtracting* a quantity, 56
mirror, polished metal or glass surface that reflects light; a looking-glass, 177
moist, slightly wet, damp; *moisten* (*v.*), make slightly wet, make damp; *moisture* (*n.*), 85
mould, hollow container into which melted substance (*e.g.* concrete†, metal, plastic†) is poured for shaping; woolly growth of non-green plant (*e.g.* green *mould* growing on old damp bread), 20, 24
mount (*v.*), fix, support, 131
mow, cut down (grass), 100

neutral, (here) neither *acid* nor *alkaline*, 53
neutralize, make *neutral*, 53
non-luminous, not giving out light, 15, 169
normal, usual, regular, ordinary, 160

occupy, take up, fill, be in (space, time, or place), 1
organic, not *mineral* or *inorganic*; to do with plants or animals; having *organs*, 108
organism, a living thing, plant or animal, 59
overlap, partly cover; cover and extend beyond, 133

palm, inner surface of hand between wrist and fingers, 127
pan, shallow vessel, 176
parallel, continuously the same distance apart, 77
particle, very small bit of matter, 18
patch (*n.*), piece of ground; also piece of cloth, *etc.*, put on to mend hole, 20
peat, incompletely decayed plant remains formed in layers under water, 109
pebble, small stone rounded by moving water, 109
peg, wood or metal pin for hanging things on, 173
physical, belonging to *physics* as *distinct* from *chemistry*, 24
physics, the study of the properties of matter and energy, 59
physicist, person skilled in *physics*, 59
plastics (*n.*), substances that are *plastic* (*i.e.* easily shaped or *moulded*) at some stage in their manufacture, 24
plus, the sign + for adding a quantity, 135
porcelain, hard white pottery, 15, 171
pore, very small opening (as in skin) through which *fluids* can pass; *porous* (*adj.*), full of tiny holes, 103
precaution, care taken in advance to avoid harm or risk, 130
prick, make tiny hole, hurt with sharp point, 127
principle, law of science, rule, 2
process, course of action, method of manufacture, 62
prop, thing used to hold something upright, 90
proportion, part of a whole, especially compared with other parts; relation between two things in size, *etc.*, 17
pungent, with sharp, stinging smell or taste, 52

radius, half the distance across a circle through the centre, 131
ratio, comparison between two numbers or quantities, *e.g.* 30 and 5 are *in the ratio of* 6 to 1, 151
reaction, effect produced by *chemical reagent*, 25
reagent, substance that *reacts* upon another and can therefore be used to test for its presence, 43, 25

refrigerator, apparatus for making and keeping food cold, 75
register (*n.*), record, 160
relative (*adj.*), comparative, 32
residue, substance that remains behind (*e.g.* after burning or filtering), 34
respond, *react* in answer, make *response* to a *stimulus*, 81
reverse (*v.*), turn the other way round; (*adj.*), opposite, 25
revise, look carefully over, with a view to correcting or improving, 168
revolve, turn round and round, 138
rigid, quite stiff, 23
rudder, movable flat piece at the back of a boat or ship by which it is steered, 160

sap (*n.*), juice of plants, 88
saturate (*v.*), cause to *absorb* the greatest possible amount of another substance; *saturated* (*adj.*), 39
sawdust, fine wood-*particles* produced in cutting wood with a *saw*, 75
scar (*n.*), mark left by healed wound, 72
scramble (*v.*), crawl and climb anyhow, 94
section, cutting; *cross-section*, view produced by cutting across anything, 23
seedling, young plant growing from seed but not yet able to make its own food, 63
senses, powers of hearing, seeing, smelling, *etc.*, 8
series, set of similar or related things, 106
set-square, *triangle* of wood, metal, or plastic used for drawing angles of 90°, 45°, 45°; or 90°, 60° 30°, 133, Fig. 73
sewage (or *sewerage*), body wastes mixed with water and carried in *sewer-pipes* or *sewers*, 108
shears (*n.*), large, strong scissors used for cutting sheet metal, for cutting wool from sheep, for gardening, 12
shot (*n.*), small balls of lead fired from a gun, 143
sieve (*n.*), wire *gauze* for separating smaller from larger particles by shaking them through the small holes in the gauze, 36
significant, having a definite meaning; important, 130, 184
sink (*n.*), *trough* with outflow pipe fixed in *laboratory bench* to take waste liquids, 166
sketch (*n.*), rough outline drawing, 167
slice (*n.*), thin broad piece (of bread, meat, *etc.*) cut off or *sliced* off, 80
slime, soft slippery mud or some substance similar to it, 109
soluble, able to dissolve, 40
solution, liquid mixture formed by dissolving; being dissolved, 28
solvent (*n.*), liquid that can dissolve other substances, 39
spark, particle of fire, 53; *sparkling*, shining and flashing, 108

sphere, ball-shaped solid, 134
spiral, winding round in the shape of a *coil*, 25
splinter (*n.*), sharp-pointed thin piece of wood split off from board, *etc.*, 10
stimulus, something that brings about a *response*, 81
stirrup, horse-rider's foot-rest; anything of same shape, 177
structure, framework; way in which a thing is *constructed* or fitted together, 59
subtract, take away from, 136
suffocate, kill by stopping supply of air to lungs, *etc.*, 47
summarize, make a short account of *essential* points, 35
survive, continue to live, 98
suspension, liquid in which *particles* of solid matter float freely *suspended* in the liquid, or *in suspension*, 38
synthesize, put together, cause *elements* to combine *chemically* (opp. *analyse*), 48

tank, large container for liquid or gas, 160
team, (here) two or more oxen, horses, *etc.*, pulling together, 127
temperate, neither very warm nor very cold, 160
thermometer, instrument for measuring temperature, 8
thread (of screw), *spiral* part of screw, 137
transplant, replant in a new place, 86
triangle, flat, *geometrical* figure with three straight sides, 15
tripod, three-legged stand, 34, 170
trough, shallow, open-topped container for liquid to stand in, 5, 175
twine (*v.*), *coil spirally* round something, 93
typical, according to type or kind, 68

uniform (*adj.*), always the same, same throughout, not changing in form or character, not *varying*, 38

vapour, *invisible moisture* in the air, gaseous form of a substance, 7
vary, change, make different, become different in degree or quality; (*adj.*) *variable*, 18
vegetative, of plants as *distinct* from animals; *vegetation*, all the plants in a certain place, 97
vertical, upright, standing upright, 131
vigour, active strength or force, 39

washer, flat ring of metal, leather, rubber, *etc.*, 133
weld, *fuse* two pieces of metal together by heating strongly their point of *contact*, 56
wilt (of plants), become soft through loss of water, lose stiffness, 86
winnow, separate unwanted light particles from heavy particles by blowing, 36

INDEX

Where there are several different page-references to the same subject, the main reference is printed in heavier type. The dagger-sign (†) in front of a word in the Index shows that this is a technical word that does not appear in the Glossary because its meaning is explained when it is first used, and also marked (†), in the text.

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